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PRODUCTION PROCESSES FOR EXTRUDING, DRAWING, AND HEAT TREATING THIN STEEL TEE SECTIONS

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TECHNICAL REPORT AFML-TR-68-293

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(U) The three-phase program concerns processes for the manufacture of thin extruded, drawn, and heat treated tee shapes. In phase I, a production manufacturing process for the extrusion of 0.062-inch-thick by 20-foot-long tee shapes in AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel was provided using a 1,200-ton Hydropress. The extrusion procedures, glass lubrication, temperature, and post-extrusion thermal and mechanical property tests are described. The results of Phase I show a relationship between alloy content, extrudability, and ram speed. AISI 4340 is the easiest to extrude and has the highest ram speed of the three alloys extruded. 18% Ni maraging steel is the most difficult to extrude and has the lowest ram speed during extrusion. The ram speed and extrudability of PH 14-8 Mo is between the two. A reproducible drawing process was refined in Phase II to reduce the thickness of the 20-foot-long tee extrusions to a target thickness of 0.040 inch. The success of the drawing phase of the program is primarily attributed to the invention of an adjustable draw die system that completely eliminates the necessity for 'pointing.' A process to heat treat 20-foot-long by 0.040-inch-thick extruded and drawn AISI 4340, PH 14-8 Mo, and 18% maraging steel tee shapes was in Phase III. The heat treat response of the three alloys is adequate and exceeds the target mechanical properties for AISI 4340 and PH 14-8 Mo.

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PRODUCTION PROCESSES
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A. L. Scow

P. E. Dempsey

FOREWORD

This final technical report covers all the work performed under Contract AF 33(615)-3159 from 30 June 1965 through 15 October 1968. The effort reported herein was initiated under Project Number 8-302, "Manufacturing Methods for the Production of Extruded and Drawn Sections of Steel". The program was administered under the direction of Messrs. T. S. Felker and K. L. Love of the Metallurgical Processing Branch (MATB), Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. A. L. Scow of the Materials Research Group of Northrop Norair was principal investigator and program manager. Mr. P. E. Dempsey, Director of Research at the H. M. Harper Company, was in charge of Harper's extrusion and drawing operations in this program. Mr. J. Boerema of Lindberg Steel Treating Company assisted in the heat treating procedures. Other personnel associated with the program were Dr. E. B. Mikus and Messrs. K. C. Wu, R. E. Rosas, and T. A. Krinke of Northrop Norair. Contributions from Messrs. K. Hookanson, L. Schilling, M. Mathisen, and T. Loos of the H. M. Harper Company also are acknowledged. The internal Northrop Norair number for this report is NOR 68-130.

This program has been accomplished as a part of the Air Force Manufacturing Methods program, the primary objective of which is to provide, on a timely basis, manufacturing processes, techniques, and equipment for use in economical production of Air Force materials and components. The program encompasses the following technical areas:

Metallurgy - Heat treating, hot ductility, and mechanical properties of AISI 4340, PH 14-8 Mo, and 18% Ni maraging steels

Equipment - Extrusion press and dies, draw bench and dies, Gleeble, and heat treating fixture

Fabrication - Extruding, drawing, and straightening

Lubrication - Glass extrusion lubricants, and drawing lubricants.

Suggestions concerning additional manufacturing methods required on this or other subjects will be appreciated.

All (or many) of the items compared in this report were commercial items that were not refined or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This technical report has been reviewed and is approved.

H. A. Johnson

H. A. JOHNSON
Chief, Metallurgical Processing Branch
Manufacturing Technology Division

ABSTRACT

This three-phase program has made available to the Air Force and industry processes for the manufacture of thin extruded, drawn, and heat treated tee shapes. In phase I, a production manufacturing process for the extrusion of 0.062-inch-thick by 20-foot-long tee shapes in AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel was provided at the H. M. Harper Company using a 1,200-ton Lowey-Hydropress. The extrusion procedures, glass lubrication, temperature, and post-extrusion thermal and mechanical property tests are described. The results of Phase I show a relationship between alloy content, extrudability, and ram speed. AISI 4340 is the easiest to extrude and has the highest ram speed of the three alloys extruded. 18% Ni maraging steel is the most difficult to extrude and has the lowest ram speed during extrusion. The ram speed and extrudability of PH 14-8 Mo is between the two. No relationship was found between ram pressure and any extrusion variable. Other Phase I activity included the development of a fast, inexpensive test method to select extrusion glass lubricants. The glass selection test method is a visual comparison of the flow, wettability, and surface reactions with known glass lubricants and provides a basis for selection. Flow stress and hot ductility data are reported. A reproducible drawing process was refined in Phase II to reduce the thickness of the 20-foot-long tee extrusions to a target thickness of 0.040 inch. The success of the drawing phase of the program is primarily attributed to the invention of an adjustable draw die system that completely eliminates the necessity for "pointing." One hundred fifteen extrusions were drawn in order to meet the thickness objective. The drawing procedures developed for the three alloys were conducted at room temperature; "warm" or "hot" drawing was not necessary. An annealing treatment was necessary to stretcher-straighten drawn AISI 4340 and PH 14-8 Mo. These thermal treatments do not lower the heat treat response of the alloys. Phase II results showed that stretcher-straightening 18% Ni maraging steel 0.040-inch-thick drawn tee shapes is possible at 1100F. The low work-hardening characteristics and small cross section of the drawn shapes limit room temperature straightening. A process to heat treat 20-foot-long by 0.040-inch-thick extruded and drawn AISI 4340, PH 14-8 Mo, and 18% maraging steel tee shapes was in Phase III. The heat treat response of the three alloys is adequate and exceeds the target mechanical properties for AISI 4340 and PH 14-8 Mo. A special tempering fixture also was designed and built to reduce any distortion to a minimum. A sub-zero (-100F) transformation unit also was designed and built to transform the PH 14-8 Mo 20-foot-long extruded and drawn shapes.

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SECTION 1

INTRODUCTION

The goals of this program were to provide economically practical manufacturing processes of extruding, drawing, and heat treating thin tee sections of steel. The processes were to be developed to an equal degree for AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel (250 grade).

Phase I of this program explored the extrusion operation. The extrusion procedures were optimized at the H. M. Harper Company using a 1,200-ton Lowey-Hydropress, Magnathermic induction billet heating equipment, glass lubricants, and precise ram speed and pressure recorders. The controllable extrusion parameters explored in conjunction with the H. M. Harper Company for the extrusion of 0.062-inch-thick tee sections for each alloy are summarized.

The effort in the drawing operation, Phase II, was also conducted at the H. M. Harper Company. The objective of the drawing operation was to provide an economical process to produce maximum quality steel tee sections by drawing. Each operation has been recorded, analyzed, and reported. The drawing process work was carried out using extruded tee sections produced during the extrusion development phase of this program and had as its objective the production of 0.040-inch thick tee sections of steel 20 feet long, equivalent to those normally supplied in other metals.

Phase III of this program was to provide heat treatment procedures to produce tee sections of mechanical properties and dimensional tolerances as specified below:

Mechanical Properties (Longitudinal)

	AISI 4340	PH 14-8 Mo	18% Ni Maraging
Ultimate Strength (psi)	260,000	200,000	263,000
Yield Strength (psi)	217,000	175,000	250,000
Elongation	6%	7%	12%

Dimensional Tolerances

Straightness of 0.03 inch per linear foot;

Twist of 1/4-inch per linear foot, 2-1/2 degrees maximum;

Flatness of 0.002-inch-per-inch crosswise dimension.

The Phase III heat treat studies were conducted in conjunction with Lindberg Steel Treating Company in Melrose Park, Illinois.

SECTION II

MATERIALS

1. EXTRUSION ALLOYS

Three high-strength, modern steel alloys were elected for extrusion in this program. The alloys are: AISI 4340, PH 14-8 Mo, and 18% Ni Maraging Steel (250 grade). All three alloys were ordered as 3.25-inch-diameter vacuum arc remelt (VAR) billet stock. A surface finish of 63 RMS and magnetic particle inspection limits of ASM 2300 were specified on the purchase orders.

Receiving inspection tests performed on extrusion billet material included chemical composition, macro and microstructure, grain size, and cleanliness rating. In addition, as-received and heat treated mechanical property data were determined. Tables I and II present the results of receiving inspection tests and the mechanical property test data, respectively.

TABLE I. CHEMICAL COMPOSITION, GRAIN SIZE, AND CLEANLINESS OF VACUUM ARC REMELT BILLET MATERIAL

Chemical Composition

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Al	Ti	Zr	Co
AISI 4340	0.41	0.65	0.014	0.005	0.18	1.70	0.85	0.20	—	—	—	—
PH 14-8 Mo	0.03	0.32	0.003	0.002	0.41	8.20	14.30	2.20	1.11	—	—	—
18% Ni Maraging	0.02	nil	0.004	0.005	0.06	17.50	—	4.80	0.07	0.43	0.02	7.72

ASTM E112-1 Grain Size

Alloy	
AISI 4340	5-6
PH 14-8 Mo	6-7
18% Ni Maraging	1-3

Cleanliness Rating

Alloy	Condition	Sulfide	Alumina	Silica	Globular
AISI 4340	thin	1-0	0-0	1-0	1-0
	heavy	1-0	1-0	1-0	1-0
PH 14-8 Mo	thin	0-0	1-1 1/2	1-1	1-1
	heavy	1-1	1-1	1 1/2-0	1 1/2-0
18% Ni Maraging	thin	1/2-0	1-1 1/2	1-1 1/2	1-1 1/2
	heavy	0-0	1/2-1	1/2-1/2	1/2-1

TABLE II. MECHANICAL PROPERTIES OF BILLET MATERIAL

Alloy	Condition	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 1 in.)	R/A
AISI 4340	550F temper	210.0	238.0	7.0	35
PH 14-8 Mo	As Received	105.0	157.0	20.0	60
	SRH 950	192.5	221.0	9.5	20
18% Ni Maraging	As Received	133.0	156.5	12.0	59
	SHT-900F age	244.0	256.2	6.0	34

Photomacrographs of the "as-received" billet stock are shown in Figure 1 for the three alloys. The macrostructure of AISI 4340 shows a considerable amount of dendritic structure in the billet center, indicating that little hot work was performed on the steel. Further micro-examination at 100- and 250-diameters magnification confirmed the dendritic structure plus a banded microstructure. Consultation with the material supplier verified that such banding is peculiar for VAR material, but that the banding does not affect the mechanical properties of heat treated material. The mechanical properties of AISI 4340 after a 550F temper, as reported above, confirm that the banding did not adversely affect the material strength and ductility.

The photomacrograph of PH 14-8 Mo shows a very fine-grained structure. Examination of the macrostructure at 100- and 250-diameters magnification revealed small pools of discontinuous delta ferrite. The ferrite content was estimated to be less than 10 percent.

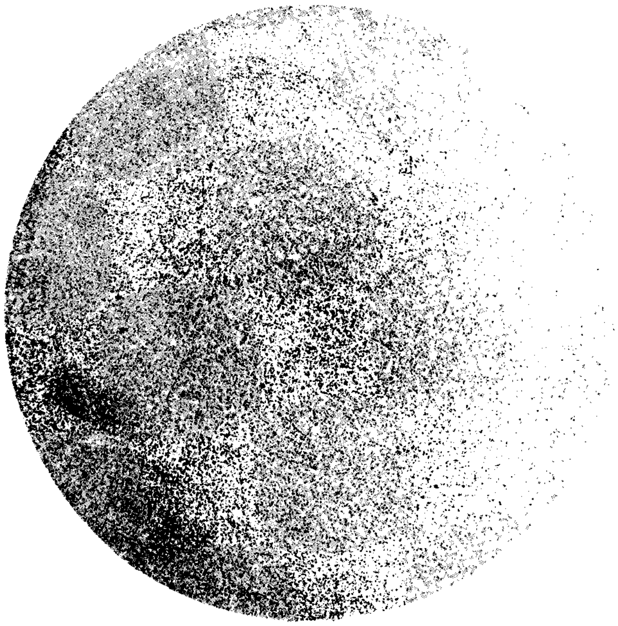
The macrostructure of 18% Ni maraging steel is peculiar. The material has large grains, banding, and evidence of non uniform hot work. The mechanical properties, however, are typical for 250-grade 18% Ni maraging steel.

2. GLASS EXTRUSION LUBRICANTS

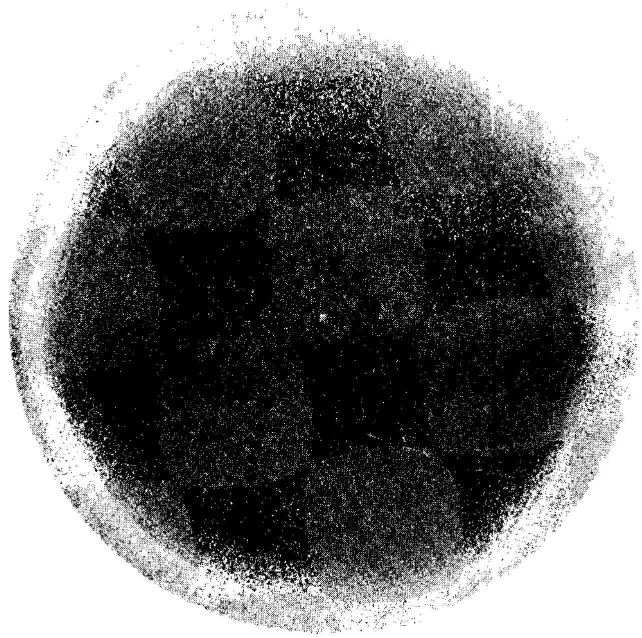
Twenty-three glass extrusion lubricant compositions were evaluated during this program. The glass lubricants were obtained from the Ceramic Chemical and Color Company. Chemical compositions were selected to cover a wide melting and viscosity range. The glass code number, melting range, and nominal composition (where available) are shown in Table III.

3. DRAWING LUBRICANTS

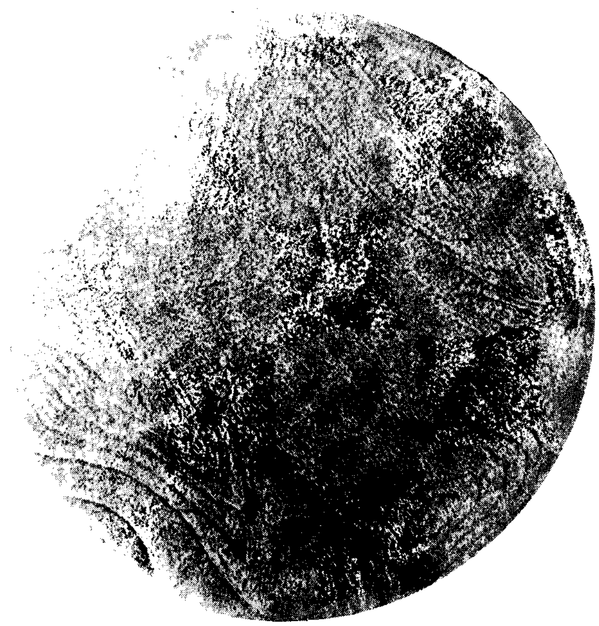
Eighteen drawing lubricants were selected for study during the drawing phase of this program. The types of lubricants include oils, graphites, disulfides, and conversion coatings used in conjunction with soap or liquid "Teflon." A listing of the lubricant trade names and the lubricant types tried before acceptable drawing lubricants were chosen is presented in Table IV.



AISI 4340
Etched with HCl
1X



PH 14-8 Mo
Etched with "Kallings"
1X



18% Ni Maraging Steel
Etched with HNO_3, 2 HCl, 6 H_2O, 1 gm Cu Cl_2
1X

FIGURE 1. PHOTOMACROGRAPHS OF "AS-RECEIVED" BILLET STOCK

TABLE III. MELTING RANGE, NOMINAL CHEMICAL COMPOSITION, AND CODE NUMBER OF GLASS EXTRUSION LUBRICANTS EVALUATED DURING THIS PROGRAM

Glass Lubricant Code Number	Melting Range (F)	Composition
N-1	1400-1500	Leadless
N-2	1600-1700	Leadless, Sodium Calcium Borosilicate
N-3	2200-2300	Leadless, Borosilicate
N-4	1500-1600	Leadless, Borosilicate
N-5	1450-1500	Leadless
N-6	3400-3500	Leadless
N-7	3000-3100	Leadless
N-8	Unknown	Unknown
N-9	1000-1100	Leaded
N-10	1500-1600	Leadless, Barium Borosilicate
N-11	1550-1600	Leadless
N-12	Unknown	Unknown
N-13	1300-1400	Leaded
N-14	1100-1200	Leaded
N-15	1200-1300	Leaded
N-16	1300-1400	Leadless
N-17	1300-1400	Leadless
N-18	1500-1550	Leadless, NaK $Si0_2$
N-19	2100-2200	Leadless
N-20	2000-2100	Leadless, NaCa Borosilicate
N-21	2100-2200	Leadless, Barium Sodium Potassium Silicate
N-22	1000-1100	Leadless
N-23	1100-1200	Leadless

TABLE IV. DRAWING LUBRICANTS

Lubricant	Type
"Metlube 806-C"	Fatty type, sulfurized, chlorinated with extreme pressure additive
"Bonderite 70"	Phosphate Conversion Coating
"Thermax 90"	30 percent Graphite and Aluminum Powder in Oil
"Vidak"	Liquid "Teflon"
"83-H"	Near-Lard – Chlorinated Emulsion
"Fel-Pro C-300"	Graphite Base Paste in Light Resin Carrier
"Texaco Drawing Compound No. 3"	Mineral Oil Base Plus Emulsifying Agents and Nonabrasive Calcium Carbonate Fillers
"Electrofilm-40"	Molybdenum Disulfide and Graphite in a Light Carrier

4. DIE COATINGS

Zirconium oxide (ZrO_2) ceramic "Rokide Z" was chosen for coating the segmented extrusion die bearing areas. High-purity zirconium oxide rod is essential to ensure a high melting point and hardness. The total porosity, that is, the total volume of open plus closed pores of the ceramic rods, was 8 to 10 percent. Most of the porosity was in the form of open pores. Typical chemical composition and basic properties of zirconium oxide are shown in Table V. The zirconium oxide material used for "Plasma"-sprayed dies was obtained from Plasmadyne Corporation and was -200 to +320 mesh.

TABLE V. TYPICAL CHEMICAL COMPOSITION AND BASE PROPERTIES OF ZIRCONIUM OXIDE "ROKIDE Z" DIE COATING MATERIAL

Chemical Composition (percent)

ZrO_2	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	NaO_2	CaO
Bal	0.63	0.33	0.33	0.39	0.02	3.7

Crystal Form:	Cubic
Bulk Density, gm/cc:	5.2
Crystal hardness, Knoop:	1000
Compressive strength, psi:	21,000
Surface finish RMS (approximately)	
As coated:	250
As sanded:	32
Melting Temperature, F:	4500
Coefficient of expansion, in/in/F:	5.4×10^{-6}
Thermal shock resistance:	Very good

SECTION III

EQUIPMENT

1. EXTRUSION EQUIPMENT

a. Extrusion Press

The H. M. Harper Company extrusion press used in this program is a four-column horizontal press of 1,200-ton capacity, manufactured by the Lowey-Hydropress, Inc. The press is a single-cylinder machine with an inserted forged steel main cylinder and has hydraulically operated container movement, die holder carrier movement, and die lock. Auxiliary equipment includes two hydraulically operated high-speed saws, a mechanized billet and dummy block loading arrangement, and a hydraulic device for separating the butt end from the dummy block. A swinging die arm facilitates placement and removal of dies and permits die changing during the ejection cycle. An air-driven brushing mechanism, automatically positioned by air cylinders, cleans the container liner between extrusions.

Power for the extrusion stroke is furnished by a 3,600-psi air-water accumulator with a total air and water volume of 175 cubic feet. Pressure for the main ram closing and auxiliary movements is furnished by a 175-psi low-pressure system. High-pressure water is furnished by an Aldrich Vertical Triplex High Pressure Pump of 115-gpm capacity and 3,600-psi maximum working pressure. It is driven by a 250-hp motor. Water is supplied to the pump from an open water tank into which the return water from the press flows.

b. Billet Heating Equipment

A Magnathermic Corporation triple-coil, two-stage, 60-cycle induction coil is employed for heating the billets. It is capable of heating carbon steel billets 5 inches in diameter and 20 inches long from room temperature to 2,300F at a rate of 4,000 pounds per hour. It operates on 160-volt, 3-phase, 60-cycle power.

Billets are heated in two stages for normal production operations. Initial heating from room temperature to 1,300F is accomplished in a single low-temperature coil with an effective length of 40 inches. Final heating from 1,300F to desired temperature is accomplished in either of two high-heat coils mounted on opposite sides of the low-heat coil. Each high-heat coil is 20 inches in effective length and arranged to heat billets singly.

The three heating coils, together with the hot billet transfer compartment, are mounted in a sealed enclosure designed to hold a helium or any other desired atmosphere under low pressure. An air-operated ram charges billets through an entry door into the low-heat coil. The charging action simultaneously ejects a heated billet onto a ramp. These billets are conveyed alternately to the two high-heat coils. After final heating, they are discharged onto a common conveyor ramp which can be radiantly heated to

prevent heat loss, and through a door onto the glassing table. All loading and ejection rams and ramp manipulations are operated by air cylinders that are controlled by the operator from a central control pulpit.

Each heating coil is provided with a Ray-O-Tube focused on the billet for temperature indication and connected to a Leeds and Northrup Speedomax temperature recorder and controller.

c. Extrusion Pressure-Ram Speed Measuring and Recording Instrumentation

Extrusion pressures are picked up from the main ram by tapping the main pressure gage line. A pressure line is then connected to a Bourdon tube in the transmitter. The tip of the Bourdon tube is mechanically linked to the end of a permanent magnet probe. A mechanical linkage translates any movement of the probe in the sensor. The distance that the probe is displaced is directly proportional to the pressure applied to the Bourdon tube. The electronic circuitry of the transmitter detects the probe position and converts it into a direct current output for recording on a Speedomax recorder.

Ram speed is produced by a tachometer attached to the extrusion press, and any forward movement of the ram results in a signal at the Speedomax recorder.

d. Press Runout and Hot Bed

The extruded section is carried away from the press to a hot bed by a long trough which moves forward on roller carriages and is capable of being rotated through an angle of 90 degrees by means of cams to discharge onto the hot bed. The extruded tee shapes are moved across the hot bed by dogs mounted on endless chains. The chains are driven by a ratchet mechanism powered by an air cylinder whose operation is synchronized with the movement of the runout trough. This system of runout and hot bed does not require the usual tee-shaped trough to prevent excessive twisting and snaking of an extrusion.

e. Stretcher-Detwister Straightener and Cold Saw

Straightening is accomplished by a Lowey-Hydropress 50-ton Hydraulic Stretching and Detwisting machine. Both the headstock and tailstock are of a hollow-head design to permit gripping an extruded section anywhere along its length for local detwisting. Because the tee extrusions (before and after drawing) are so thin, special Hufford jaws were installed in the grips of the Stretcher-Detwister to grip the extrusions on all three surfaces. The Hufford jaws are actuated by an air supply and close evenly on the base and stem of the tee section. The Hufford jaw arrangement effectively prevents any slipping of the thin tee shapes during straightening. The machine has a stretching capacity of 100,000 pounds and a stroke of 60 inches on the headstock cylinders. It is capable of handling bars of a size that can be contained in a 4-inch-diameter circle in lengths up to 50 feet. Rotation of the detwisting heads is limited in both directions at a speed of 1.5 to 3 rpm and capable of exerting 4,000 foot-pound detwisting torque. Stretching speed is adjustable up to 55 feet per minute.

The stretcher-straightened extrusions are cut to length or trimmed on a high-speed friction saw designed by Lowey-Hydropress, Inc.

f. Glass Removal

Removal of glass remaining after straightening is accomplished in an American Wheelabrator shot-blast unit. This machine consists of four 19.5-inch-diameter by 2.5-inch-wide wheelabrator units. The units are mounted above and below and to either side of the pass line of the work to clean the entire periphery of the tees of irregular cross-sections. A work conveyor is arranged to carry six extruded tees at a time through the unit at speeds from 15 to 45 feet per minute.

Standard acid and caustic cleaning tanks also are available for cleaning extruded and extruded and drawn shapes.

g. Temperature Sensing

In addition to the Leeds and Northrup Ray-O-Tube used to measure and control the temperature of the billets in the final heating coil, a portable Leeds and Northrup optical pyrometer is used to measure the billet surface temperature immediately before being charged into the container of the extrusion press.

Another Leeds and Northrup Ray-O-Tube is mounted directly over the exit side of the die holder, 27 inches from the back face of the die, to measure extrusion exit temperatures. This unit can measure the temperature of either stationary or moving surfaces. The Ray-O-Tube has a high speed of response (time constant: 0.15 second) and is particularly applicable to measuring extrusion exit temperature where the temperature will vary along the extruded shape.

h. Principal Extrusion Tooling

The extrusion press stem used in this program is H-12 hot-worked die steel heat treated to a Rockwell hardness of 47-50 R_c. The stem was designed to a minimum compression stress of 180,000 psi. Because higher stem pressures were anticipated to complete the program and there was always the possibility of breaking a stem, a second one was ordered of 18% Ni maraging steel. The backup stem has the same dimensions and surface finish as H-12, but has a minimum design stress of 200,000 psi.

Two dummy blocks were designed, cast in HMH Number 53 hot hardness steel, and heat treated to a Rockwell hardness of 45-47R_c. The dummy blocks were machined to 63 RMS surface finish.

An H-12 hot-worked die steel liner was forged and purchased from Allegheny Ludlum Steel Company, Ferndale, Michigan. The liner was machined to 3.406-inch-diameter bore and 15 inches in length. The outside diameter was taper-machined from 8.625 inches to 7.898 inches for an interference fit of 0.020 inch in the container. The outside surface was finished to 63 RMS while the bore and seat for the die holder were finished to 16 RMS.

An AISI 4340 steel container heat treated to 32-37 R_c was machined to fit the small liner required for this program. It was bored to a tapered hole from 8.625 inches at one end down to 7.878 inches at the other end. The container is 31 inches long and 25 inches in diameter. Because the liner is only 15 inches long, a cradle was made

to support the billet during transfer into the liner. The cradle is non-stressed tooling and was made from carbon steel welded and machined to fit into the grooves in the enlarged diameter of the stem.

2. DRAWING EQUIPMENT

a. Draw Bench

An Aetna-Standard draw bench of 50,000 pounds capacity was used to draw the extruded tee steel shapes. The draw bench has a drop-hook-type carriage assembly with an air-actuated Hufford gripper head mounted on the carriage. The jaws have 1/16-inch diamond points in Potomac M steel nitrided to a hardness of about R_c 70.

The draw force is applied by a 225-hp GM diesel engine through a "Power Flow" acceleration control and transmission system. The horsepower output from the diesel engine increases rapidly at low shaft speeds and then remains approximately constant over the remainder of the speed range. The "Power Flow" clutch (manufactured by Mid-States Industrial Clutch Company, Wichita, Kansas) operates by introducing air into the clutch diaphragm cavity. As the air expands, the diaphragm compresses the release springs and contacts the friction linings with the pressure plates. The torque capacity of the clutch is directly proportional to the air pressure available at the clutch. The acceleration control system also includes a five-speed transmission. This power control system ensures a constant force on the extrusions, prevents any dynamic loading, and has reduced greatly the extrusion breakage due to overload when the chain is dropped.

b. Holding Furnace

A 23-foot-long Lindburg/Hevi-Duty holding furnace was used for heating the extrusions. The furnace is separated into five zones of control. The end zones are 70 inches long and rated at 3.4 kw each. The center zones are 48 inches in length and are rated at 5.6 kw. The total input is 34.8 kw, and a maximum operating temperature of 1850F is possible with the furnace. The furnace was originally intended to be used for the warm-drawing of the extrusions. However, because the drawing operation has since been developed at room temperature, the holding furnace has been used extensively for "in-process" annealing thermal treatments of PH 14-8 Mo and 18% Ni maraging steel tee shapes. The inside diameter of the hinged furnace cavity is 5-3/4 inches with 4 1/2-inch vestibules at each end. A 24-foot-long, 4-inch-diameter Incoloy tube was installed in the furnace cavity by removing retainer bolts at the center hinge line of the furnace.

The temperature in each section of the furnace is controlled by Barber-Coleman model 472P true proportioning controllers. Temperature control is rated at ±10F over the entire temperature range.

3. LABORATORY EQUIPMENT

a. Gleeble (Time-Temperature-Strain Duplicator)

The Gleeble is basically a simulation device used to determine the effect of any given thermo-mechanical history on the mechanical properties or the microstructure of a metal.

The Gleeble consists of a high-speed time-temperature control device coupled with a high-speed load-applying device. Tests can be conducted at strain rates varying from 0.01 sec^{-1} to 20 sec^{-1}, thus duplicating a wide range of time-temperature extrusion conditions. The test specimen is heated by its own resistance by a pre-programmed electrical current. A thermocouple is attached to the surface of the specimen to monitor and control the test temperature.

The measured temperature is calibrated against the programmed temperature to provide a differential control system which allows for heating rates as high as 3000F per second with an accuracy of ±15F from the programmed temperature.

Loads and strain rates were programmed into the Gleeble so that optimum time and temperature for the extrusion of steel alloys could be estimated readily. The loads, temperatures, and strain achieved during test are recorded on a high-speed multichannel oscillograph. The reference generator, which is a programming temperature control system, can be programmed so that the cooling rate of the billet from the soaking furnace to the extrusion press can be duplicated as a function of transfer time.

4. HEAT TREATING EQUIPMENT

a. Gantry Furnace

The heat treating furnace used to process all the 20-foot-long extrusions is located at the Lindburg Steel Treating Company in Melrose Park, Illinois. The gantry furnace accommodates a loading fixture with an effective work load of 6-1/2 feet in diameter by 24 feet in length. The pots below the gantry furnace house the loading chamber, salt quench tank, water wash stand, and temperature furnace. The furnace is atmosphere-controlled and rolls on wheels along tracks that straddle the pots. It is electrically heated, has five control zones of 115 kw each, and operates between 250 and 2050F. The alloy hook which raises and lowers the loading fixture and extruded tee sections in and out of the furnace is driven by a variable-speed dc motor. The quench rate used on the AISI 4340 extrusions was the maximum capacity of the motor, or 80 feet per minute. An endothermic-type protective atmosphere is introduced into the furnace to maintain an equilibrium carbon potential with the 4340 steel tee sections.

The electrically heated tempering furnace operates between 300 and 1,450F. This furnace is designed so that parts can be stress-relieved or tempered in an inert atmosphere such as nitrogen.

b. Tempering Fixture

A tempering fixture designed to reduce the distortion of the extruded and drawn tee shapes was designed and made of heat-resistant alloy steel. The fixture has a series of clamps to restrain the movement of the drawn shapes. The fixture will accommodate two extrusions per tempering cycle and will minimize the distortions resulting from thermal gradients between the thin tee flanges and the thicker intersection of the flange and web.

c. Subzero Transformation Unit for PH 14-8 Mo

A 22-foot-long, 5-1/2-inch-diameter aluminum tube has been designed with copper tubing cooling coils to reach and maintain the transformation temperature

of -100F for PH 14-8 Mo alloy. The temperature is maintained by a controllable flow valve for liquid nitrogen. The outside of the aluminum tube is insulated to maintain the -100F for the eight-hour transformation cycle. Temperature variation is designed to be less than five percent over the operating temperature range.

SECTION IV

EXTRUSION PROCESS

The specific object of the extrusion phase of this program was to extrude three steel alloys into 20-foot-long 0.062-inch-thick tee shapes. The three alloys that have been extruded are AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel.

1. STANDARD EXTRUSION PROCEDURES

a. Accumulator Pressure

The first step in extrusion press setup is to establish the maximum accumulator pressure. The accumulator pressure establishes the load on the stem and, hence, must not exceed the allowable strength of the stem material. The stem made of H-12 hot-worked die steel was heat treated to operate at a maximum stress of 180,000 psi. The calculation to determine the accumulator pressure is shown below:

Area of stem	8.3 sq. in.	
Area of main ram	562 sq. in.	
Load (180,000 x 8.3)	1,494,000 lb	
Accumulator Pressure	1,494,000 lb	= 2650 psi

Therefore, the accumulator was set not to exceed the 2,650-psi pressure during the trials conducted, when using the H-12 stem. The maximum accumulator pressure possible when using the higher strength backup maraging steel stem was 3,000 psi.

b. Container Temperature

Preheating the container-liner was started 12 hours prior to the scheduled extrusion time so that the liner temperature would be stabilized. The container temperatures were varied from a maximum of 1000F to a minimum of 500F. Container temperature first was thought to be a major extrusion variable that would require precise control. Experimentation early in the program, however, proved that the container temperature need not be controlled carefully. To prevent chilling of the billet and solidification of the glass lubricant, the standard operating temperature fluctuated between 500 and 600F.

c. Billet Handling

Billet handling procedures were not varied during the course of this program. After the extrusion bar stock had been cut into seven-inch lengths, they were identified, degreased, and wrapped in paper. The billets were unwrapped immediately before charging into the furnace heating coil and handled with clean gloves to prevent any oil or dirt contamination. (The billet "nose" configuration was varied during the extrusion process development and is discussed in a later section.) After the billet was charged

into the heating coil, a positive gas (nitrogen or argon) pressure was continuously maintained during the billet heating cycle. After the billets were heated to the desired temperature, they were discharged from the furnace, picked up with a pair of tongs, and placed on the glassing table. The heated billets rolled down the inclined glassing table and picked up the lubrication glasses. The glass-coated billets were picked up again with a pair of tongs and placed on the cradle inside the container. The dummy block was put in back of the billet and the ram closed on the billet.

d. Glass Handling

Extrusion lubricant glasses are grouped conveniently into two classes; namely, "roll-down" glass and "die-glass." The roll-down glass is defined as the lubricant between the billet and the liner walls. All roll-down glass lubricants evaluated were approximately the same fineness of -200 mesh. The roll-down glass was sprinkled on the glassing table and hand-leveled by using a sawtooth-edged glass spreader. The height of the leveled glass was maintained at approximately 0.025 inch at all times to ensure complete glass coverage of the billet.

The die-glass "pads" were prepared by mixing the ground glass with sodium silicate as a binder, compacting the mixture in a mold, and finally placing them in a 200F oven to drive off any moisture and harden the die-glass pad. The molded die-glass pads were identified carefully to prevent mix-up because they all look nearly identical, but have very different melting and lubrication characteristics. The amount of glass used to make the pads varied depending on the configuration being investigated and the type of glass used. Generally, the die-glass pads required between one and two ounces of glass to make up the various configurations. (The die-glass configurations and glasses tried are discussed in detail in the lubrication section of this report.)

e. Die Design, Coating, and Handling

The detailed die design selected for this program is shown in Figure 2. The die was designed to accomplish the dual function of maintaining both the proper flow of metal through the die and a uniform distribution to all areas of the die. The three-segment dies were precision-investment-cast cobalt-base alloy ALX-6. Each of the mating surfaces was ground to half of the required thickness. The die segments were assembled, spot welded on the front and back faces, chucked in a lathe through the relief hole, and turned to the required diameter. (Cobalt base alloys are non-magnetic and require the special machining and tooling procedures described.) The dimensions were controlled to just fit the die holder. Grip marks were ground into the outside-diameter surface and the die locked into a carbon steel jig to surface grind the back faces. The back surfaces of the dies were ground so that the die with the backer protruded from the die holder from 0.015 to 0.30 inch. Each set of dies was etched for identification, and the weldment was ground off the die face with a hand-held air grinder.

The die segments then were cleaned, shot blasted, and coated to from 0.007- to 0.008-inch thickness with the zirconium oxide "Rokide" process. The zirconium oxide die coating was applied over an intermediate substrate on some of the dies used in the program. The coatings were applied by using a Mogul R-2 Turbo-Jet Rokide gun. The coatings were produced by heating the end of a solid rod to a fusion temperature and projecting the molten particles at a very high velocity against the die surfaces. The particles solidify and tightly adhere to the die surfaces. The surfaces of the coated dies were hand-polished with emery cloth to an estimated roughness of RMS 16. The coated dies then were assembled in the die holder and dimensionally checked on an

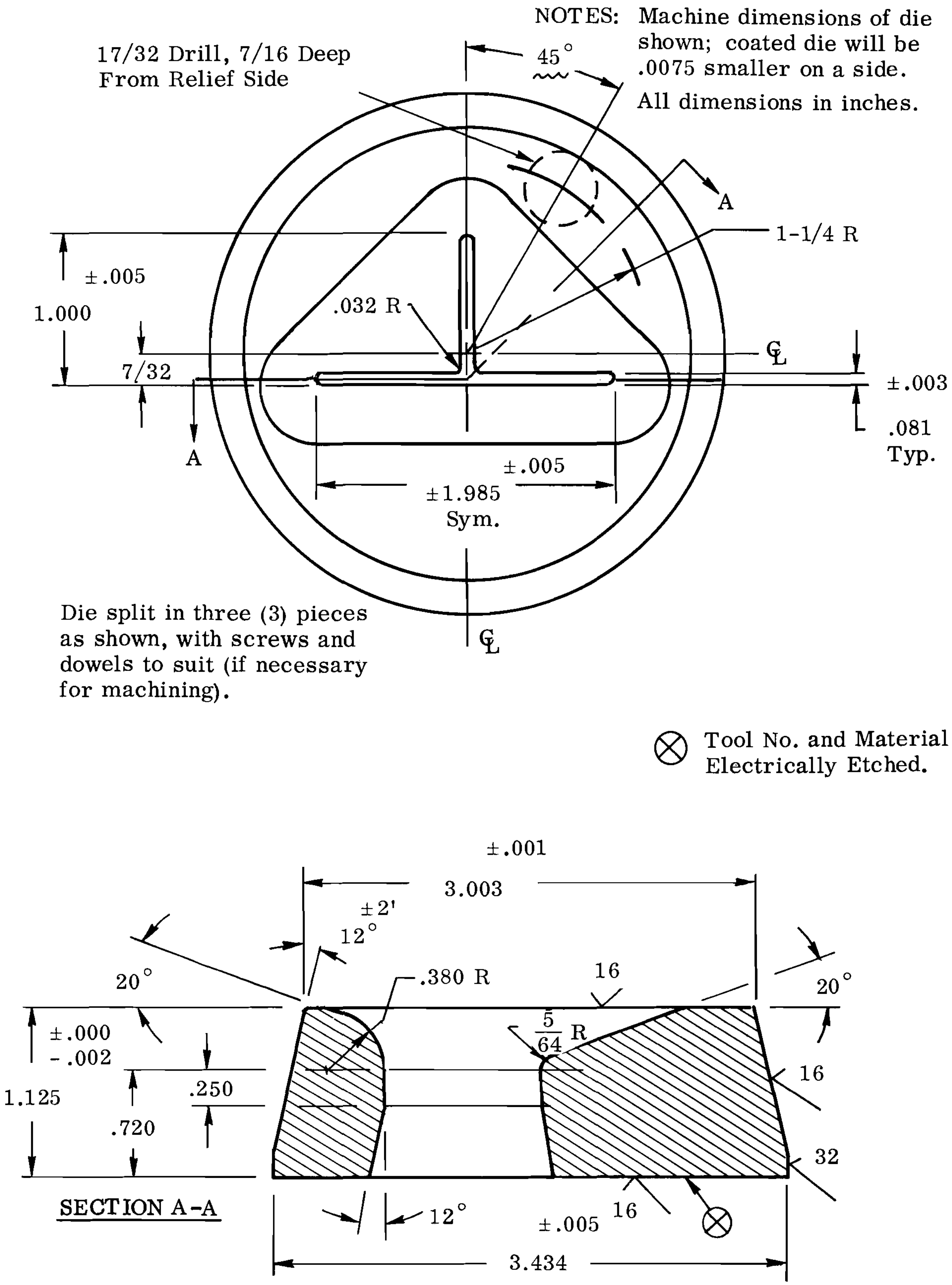


FIGURE 2. EXTRUSION DIE CONFIGURATION AND DIMENSIONS

optical comparator. A photograph of the coated die in the die holder and carriage is shown in Figure 3.

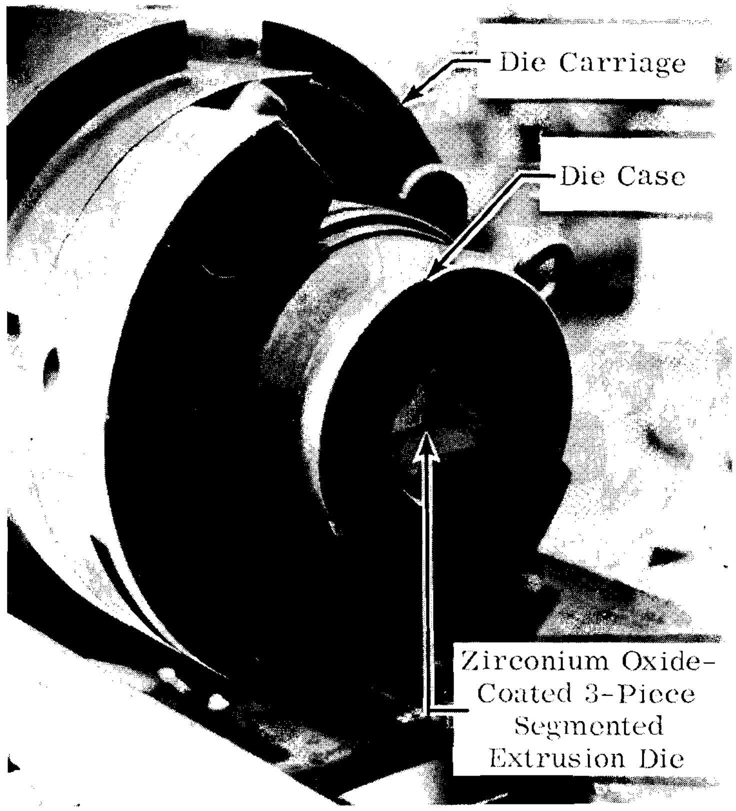


FIGURE 3. VIEW OF EXTRUSION DIE SETUP IMMEDIATELY BEFORE LOCKING INTO THE EXTRUSION PRESS

f. Ram Speed and Pressure

Minimum and maximum ram speeds were recorded for each billet extruded during the program. The minimum ram speed is defined as the speed of the ram at upset. The maximum ram speed is the top speed of the ram during extrusion. Figure 4 presents a typical ram speed record. The record shows that the entire billet is extruded in one second and the ram speed increases from 1.4 inches per second to 7.2 inches per second during the extrusion of the billet.

Ram pressure recordings also were obtained for each billet extruded. A typical example of the ram pressure records is presented in Figure 5. The extrusion run time is less than one second and note the characteristic high "breakthrough" pressure and lower run pressure.

Ram speed data are considered a better measure of the materials' resistance to flow than ram pressure, particularly for 18% Ni maraging steel. In reducing the ram speed data, maraging steel extrusions were classed as (1) acceptable, defect-free, (2) torn shapes, and (3) stalls. The ram speed and pressure data were analyzed and are summarized as follows: (1) Increasing the ram pressure does not increase the ram

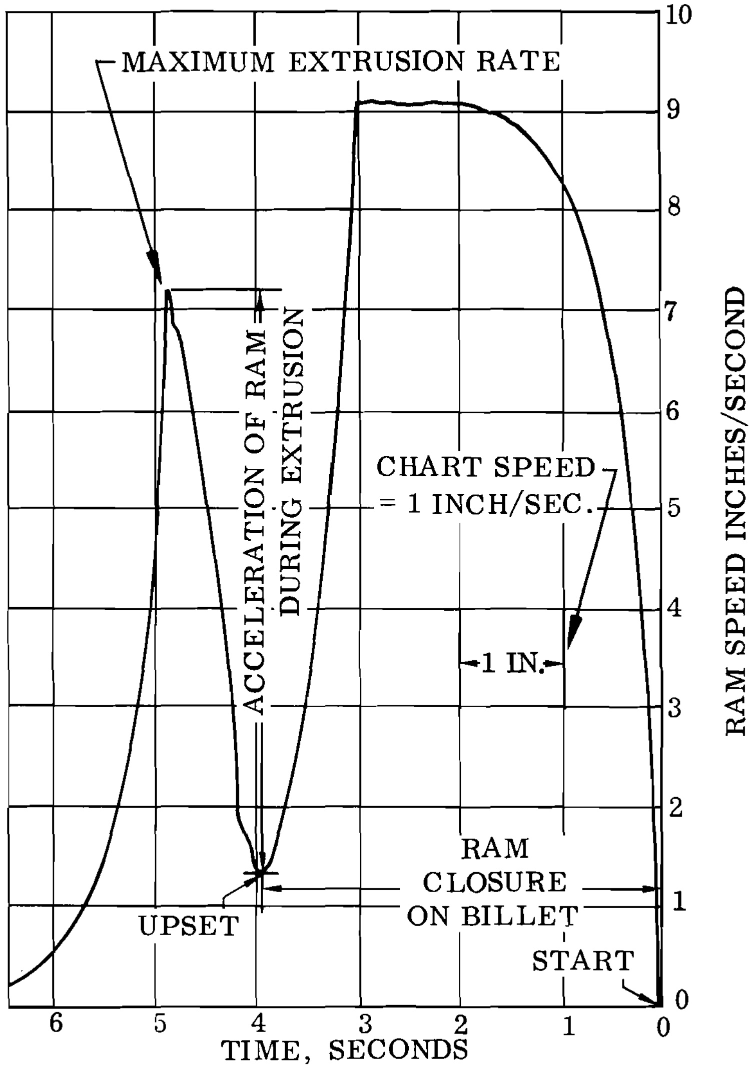


FIGURE 4. TYPICAL RAM SPEED RECORD FOR AISI 4340

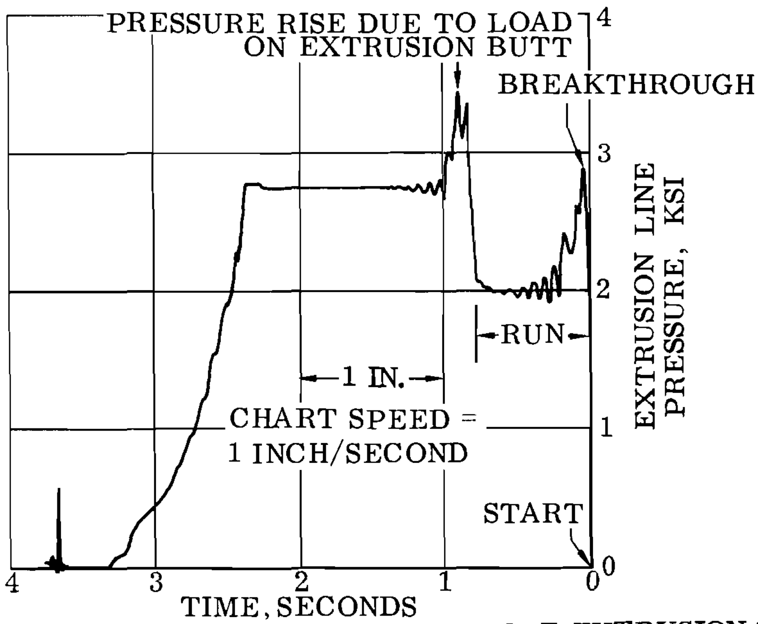


FIGURE 5. TYPICAL LINE PRESSURE RECORD FOR THE EXTRUSION OF AISI 4340

speed nor improve maraging steel extrusion quality. Acceptable full-length extrusions can be produced at average pressures of 2900 psi. (2) The extruded shapes that were torn had an average breakthrough pressure of 300 psi lower than the pressure of acceptable defect-free extrusions. (3) The average ram speed for torn defective tee extrusions is twice as fast as the group of acceptable extrusions. The torn group ram speed average is 4.1 inches per second, compared to 2.2 inches per second for the acceptable group.

A complete record of extrusion trials is presented in Appendix I. A summary of the controllable extrusion parameters established for the extrusion of AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel on the H. M. Harper 1,200-ton extrusion press setup is presented below:

Extrusion Parameter	AISI 4340	PH 14-8 Mo	18% Ni Maraging
Billet Temperature Range	1950-2250F	1975-2250F	2075 ±25F
Furnace Atmosphere	Dry Nitrogen	Dry Nitrogen	Dry Nitrogen
Container Temperature	500-600F	500-600F	500-600F
Extrusion Ratio	45:1	45:1	45:1
Ram Speed (Average)	5.0 in/sec	4.0 in/sec	2.2 in/sec
Die Design	20° Entrant on Flat Face Die	Same	Same
Transfer Time (Typical)	18 sec	18 sec	18 sec
Die Coating	Zirconium Oxide	Zirconium Oxide	Zirconium Oxide
Lubricants			
Billet Liner	N-5 Glass	N-5 Glass	N-5 Glass
Billet Die	N-16 Glass	N-16 Glass	N-16 Glass
Ram Pressure	2650 psi	2650 psi	2650 psi

2. GLASS LUBRICATION

a. Glass Screening Test Procedures and Results

The selection of glasses for use as extrusion lubricants commonly has been based on viscosity and experience. However, little or no information is available in literature on what the viscosity must be to qualify as an extrusion lubricant. A recent study[1] was conducted to determine if pressure adversely affected the viscosity and lubricity of candidate glasses. The conclusion of the report is that viscosity and determinations of

[1] R. F. Huber, J. L. Klein, P. Loewenstein, Development of an Improved Manufacturing Process for the Hot Extrusion of Alloy Steel Structural Shapes, Whittaker Corp., Nuclear Metals Division, Technical Report AFML-TR-67-79, March 1967

diverse compositions show that pressures of the magnitude encountered in the extrusion of steel have no significant effect on the viscosity of glasses. This means that viscosity data cannot be considered as a critical parameter in the selection of a glass lubricant.

Evaluating glass lubricants by using an extrusion press is the best technical approach, but obviously it is economically and practically prohibitive. Other glass properties and test procedures, therefore, were established to screen the large number of candidate glass lubricant compositions.

An ASTM test procedure developed in 1955 was selected and modified to screen the candidate glasses. The test procedure is titled "Standards of Test for Fusion Flow of Porcelain Enamel Frits," (Button Flow Methods), ASTM designation C 374-55T (1955). Typical examples of the glass screening test panel results are shown in Figure 6. The figure illustrates the wide range of flow and wetting characteristics possible for similar glass compositions.

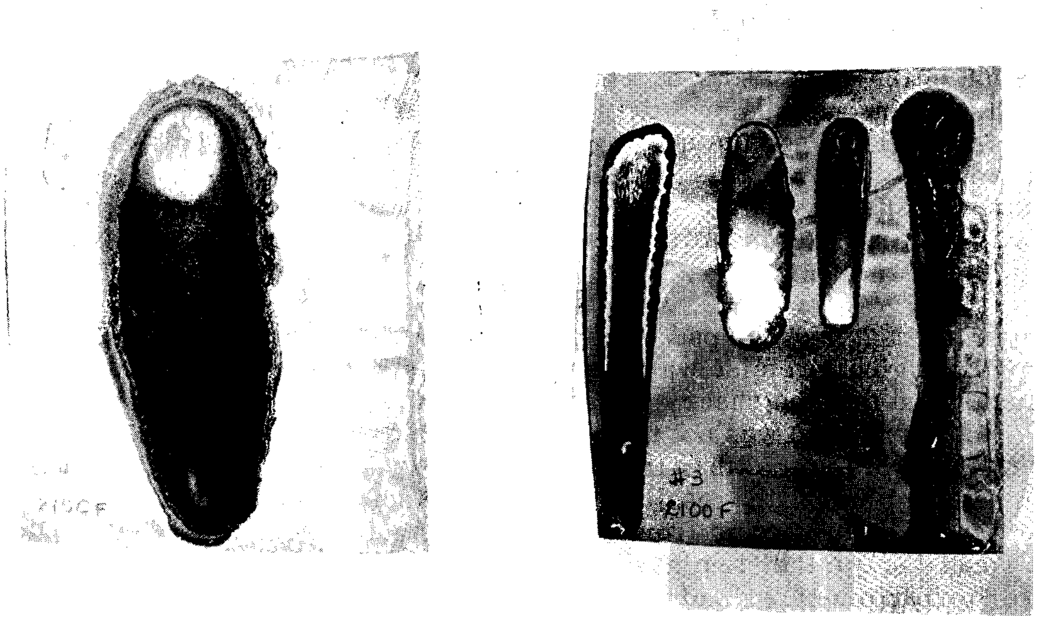


FIGURE 6. TYPICAL EXAMPLES OF GLASS SCREENING TEST PANELS

The results of the glass screening tests were grouped into three categories: those acceptable as die glasses, those acceptable as billet roll-down glasses, and those not acceptable for either application. The criteria used in classifying the glass results were observations such as length and width of flow, color changes, residues, shrinkage characteristics, and any obvious reaction with the PH 15-7 Mo substrate. The candidate glasses also were assessed based on a visual comparison with the results of accepted standard day-to-day production operation glass lubricants.

The glasses selected by the test procedure described above were used during the extrusion process development. The roll-down glass that performed well consistently was leadless N-5, which has a melting range between 1450 and 1500F.

b. Glass Lubricant-Billet Chemical Compatibility

A compatibility test of AISI 4340 steel with different glasses was conducted at 2100F to determine if there is any incompatibility between the glass lubricants and the AISI 4340 steel. Any reaction of the glass lubricant would affect adversely the mechanical properties of the extruded shape and the lubricating characteristics of the glass. The compatibility test procedure consisted of placing 3.5 grams of compacted glass in 0.75-inch-diameter by 0.4-inch-deep holes drilled in a 0.55-inch-thick plate. The plate with the glass samples in the holes then was placed in a furnace for 30 minutes, removed from the furnace, and air-cooled. The samples were examined visually, sectioned, mounted, and examined at 100- and 250-diameters magnification. Only one glass appeared to have reacted with the AISI 4340 steel. A microhardness traverse was run on this sample from the edge of what appeared to be a reaction product toward the unaffected metal. No hardness increase or decrease was noted from the surface to the base metal.

c. Die Glass Pad Design Optimization

The function of the die-glass pad is to provide a source or reservoir of glass to lubricate the die continuously during extrusion. Whether or not the glass performs this function is dependent upon the melting characteristics of the die glass and the dimensions of the pad. The laboratory glass screening study results established that five different compositions would melt in the time and at the temperature of extrusion. Therefore, the first extrusion trial used glass N-16. The configuration of the die-glass pad is shown in Figure 7.

The hole in the center of the pad is to hold the pad on a rod to place it in the hot container. The original premise was that an excess of glass in the pad would not affect the extrusion and that the shear strength of the glass would not be high enough to plug the die. However, such was not the case. On the first extrusion trial, the die glass plugged the base of the tee (thus increasing the extrusion ratio to about 150 to 1 on the stem area not blocked), resulting in about 20 feet of ribbon, while the balance of the billet landed down-stream from the press in small pieces of melted AISI 4340. The die was washed out in the stem area. A photograph of the plugged die design is shown in Figure 8. The die-glass pad was reworked to eliminate any glass immediately over the die openings. The inside diameter of the glass, therefore, was increased to two inches. A schematic diagram of the second die-glass pad design is shown in Figure 9(a). This glass configuration also plugged the die. The conclusion, therefore, was that the amount of glass as well as the design were important. The die-glass pad was redesigned using one ounce of glass and including an 0.75-inch radius, corresponding to the radius of the billet "nose." The extrusions made using this configuration were of good qualify, but resulted in some inconsistencies in completely filling the base of the tee.

The primary function of the die-glass pad is to lubricate the die. Evidence of the areas lubricated could be seen readily by examining the extruded tees for melted glass. All of the extrusions produced using the configuration shown in Figure 9(b) (as well as the pad designs) resulted in glass-free or bare extrusion surfaces. The surface finish was consistently better than the required RMS 100, even though the glass was not evidenced on the extruded product. This led to the conclusion that the die glass does not melt and flow through the die on the extrusion surfaces. The function of the die-glass pad is to provide a smooth flow pattern for the billet material. The optimized die-glass pad

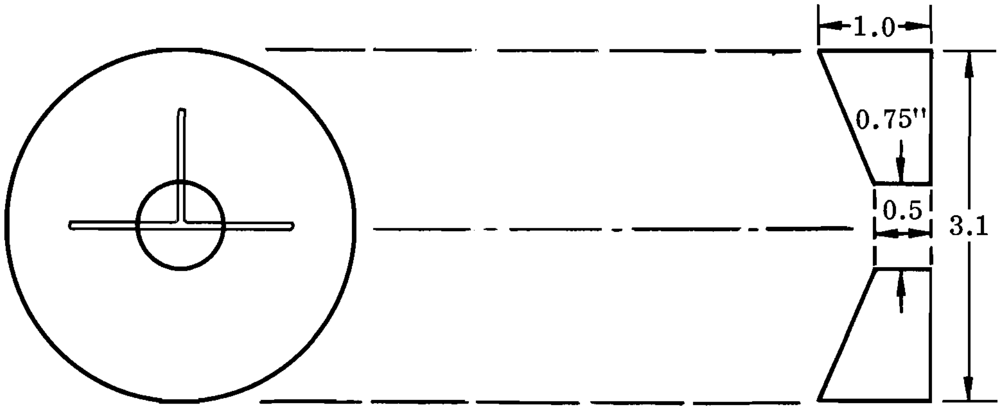


FIGURE 7. SCHEMATIC VIEW OF FIRST DIE-GLASS PAD DESIGN EVALUATED

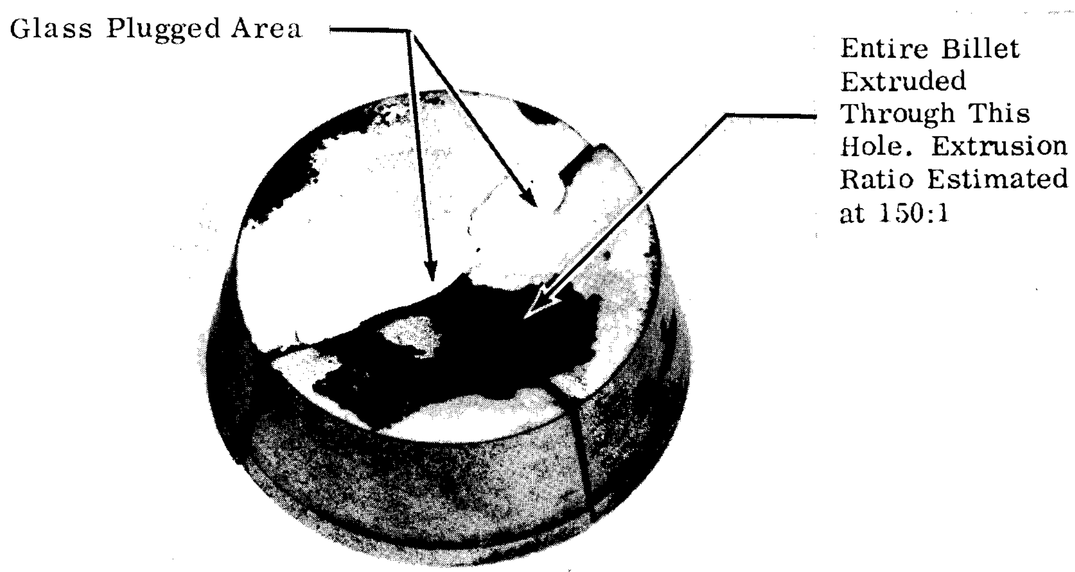
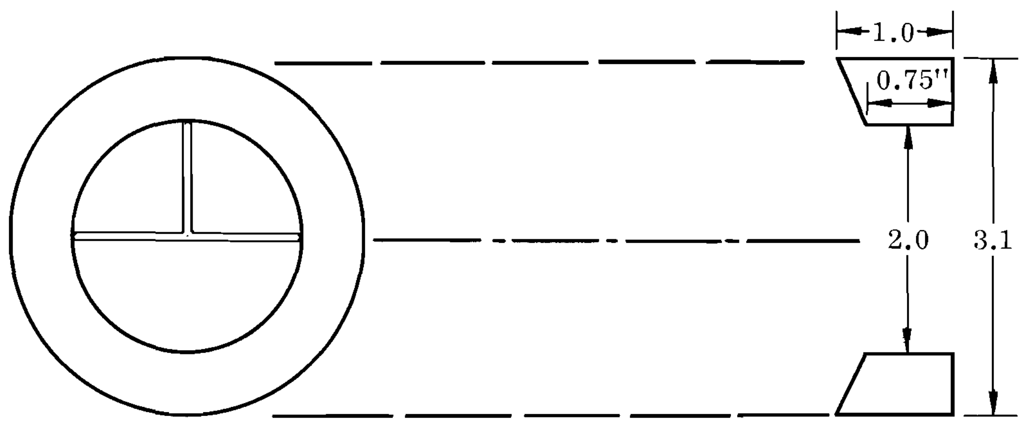
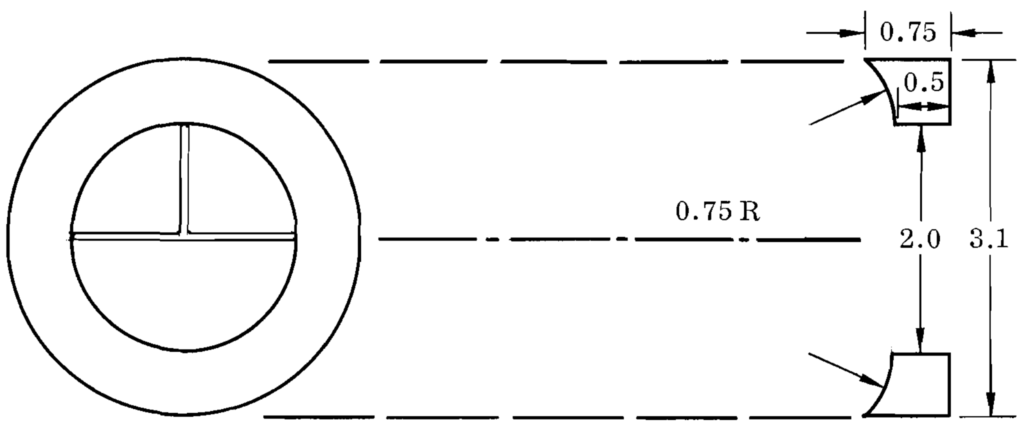


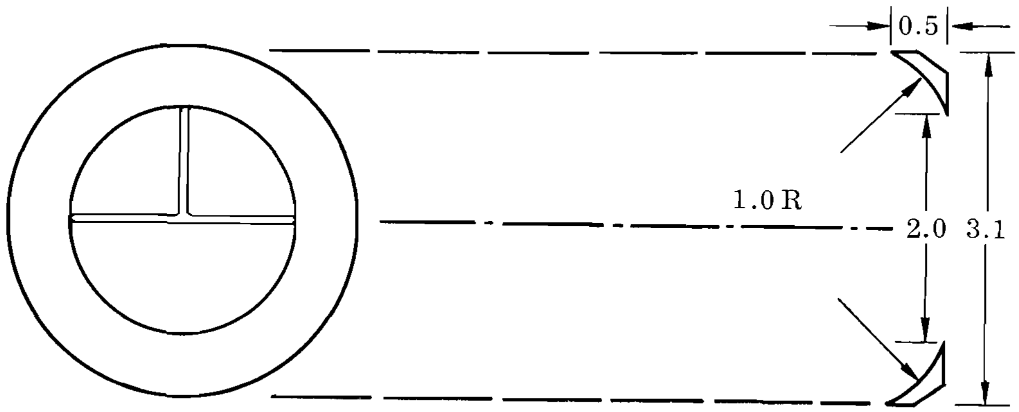
FIGURE 8. PHOTOGRAPH OF GLASS-PLUGGED SEGMENTED DIE



(a) View of second die-glass pad design. This pad also plugged the die.



(b) Third glass-pad configuration designed to correspond to the radius of the billet "nose."



(c) Optimized die-glass pad design. Both billet nose and die-glass pad have one-inch radii.

FIGURE 9. SCHEMATIC VIEWS OF DIE-GLASS PAD DESIGNS

design is shown in Figure 9(c). The glass pads made to this configuration are fragile and must be handled with care.

To verify the conclusion that the lubricant at the die does not lubricate the surfaces and is not necessary to produce an acceptable surface finish, one AISI 4340 billet was extruded without the glass pad. The resulting extrusion was 27 feet long and had a very good surface finish. A cross section of the butt discard is shown in Figure 10. A PH 14-8 Mo butt is included for comparison to show the flow pattern when using an optimized die pad. Note there is no "dead-metal" zone commonly referred to in the literature on each butt material. The butt was cut intentionally to show the most severe area of deformation.

3. TEMPERATURE

a. Ductility and Flow Stress at Extrusion Temperatures

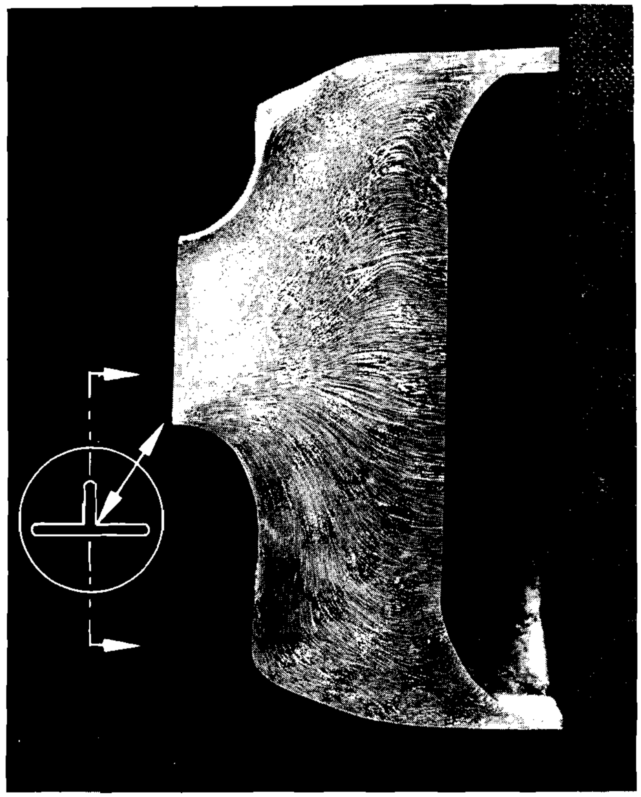
The ductility of a metal being deformed at elevated temperature depends on strain rate, temperature, and microstructure. To determine this relationship on an extrusion press is expensive and complicated due to such variables as lubrication, tooling, ram speed, etc. The Gleeble can evaluate these extrusion factors on small specimens with controlled variation of process variables and thereby provide an approach for extrusion press operations on full-scale extrusion trials. The specimens used for this test were four inches long and 1/4-inch in diameter, threaded on both ends to facilitate holding in the specimen grips. The specimen is heated by its own resistance to the passage of pre-programmed electrical current. A thermocouple is welded to the center of the heating zone to monitor and control temperature. The temperature gradients over the one inch of heated zone are ± 15F. The measured temperature duplicates the programmed billet heating rates and extrusion temperatures of 1900F, 2100F, and 2300F.

Figures 11 and 12 show a comparison between the 18% Ni maraging steel, PH 14-8 Mo, and AISI 4340 flow stresses versus test temperature for 1-sec^{-1} and 6-sec^{-1} strain rates, respectively. It is obvious from these results that the extrusion of maraging steel requires a higher pressure than AISI 4340 at the same temperature. This primarily is due to the solid solution strengthening of the 18-percent nickel in the maraging steel. Figures 11 and 12 show that the flow stresses for maraging steel and PH 14-8 Mo and AISI 4340 are strain-rate- and temperature-sensitive. At 1-sec^{-1} strain rate, the flow stress of 18% Ni maraging steel is much more temperature-sensitive than AISI 4340 steel. At 6-sec^{-1} strain rate, the temperature-dependence is less.

The elongation versus test temperature for AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel for 1- and 6-sec^{-1} strain rates is plotted in Figures 13 and 14, respectively. Flow-stress data indicate equipment capacity required to make an extrusion. Elongation data are also a parameter for the evaluation of the flow characteristics of the alloys to be extruded. The elongation of AISI 4340 for 1-sec^{-1} shows an increase with increasing temperature from 1900 to 2300F. These data parallel the flow stress data of Figures 11 and 12 which show that the flow stress of AISI 4340 at 1-sec^{-1} is relatively temperature-insensitive between 1900 and 2100F.

The elongation of 18% Ni maraging steel is also strain-rate-sensitive. At 1-sec^{-1} the elongation is almost constant for all three test temperatures. At a strain rate of 6-sec^{-1}, however, the elongation increases from 36 to 48 percent at 2300F test temperature.

AISI 4340 Butt Cross Section. Billet extruded without die-glass pad. Note there is no "dead-metal" zone.



PH 14-8 Mo Butt Cross Section. Billet extruded with die-glass pad. The metal flow pattern is much smoother than that shown above for AISI 4340.

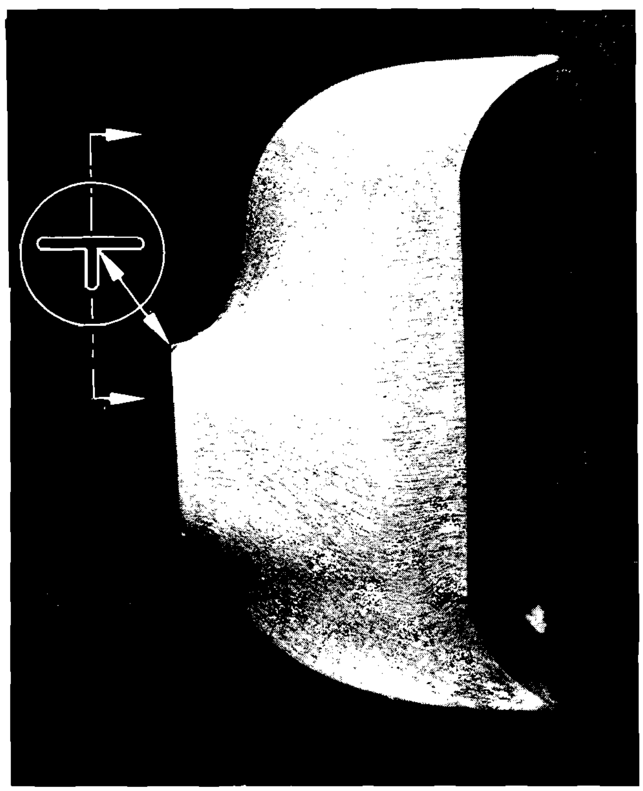


FIGURE 10. PHOTOGRAPHS OF BUTT CROSS SECTIONS, WITH AND WITHOUT A GLASS PAD NEXT TO THE EXTRUSION DIE

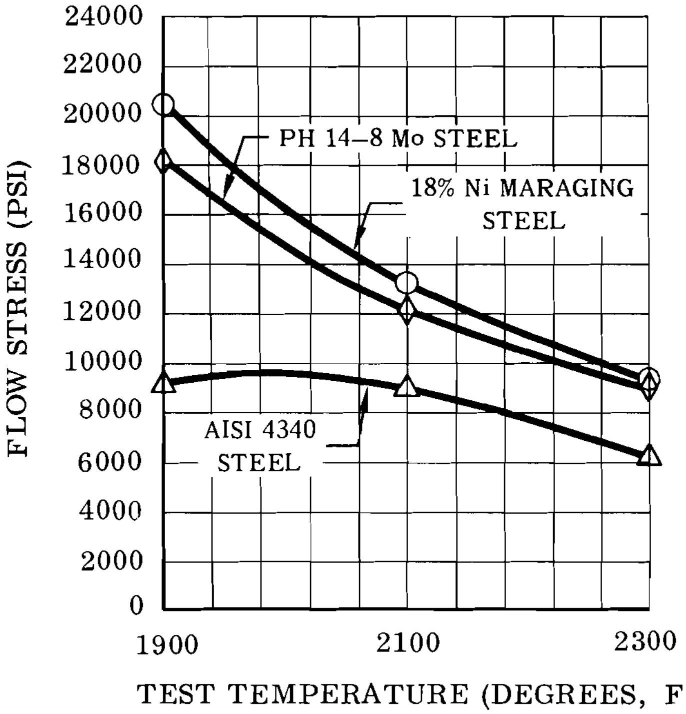


FIGURE 11. HOT DUCTILITY GLEEBLE DATA: FLOW STRESS VS TEST TEMPERATURE FOR 1-SEC^{-1} STRAIN RATE

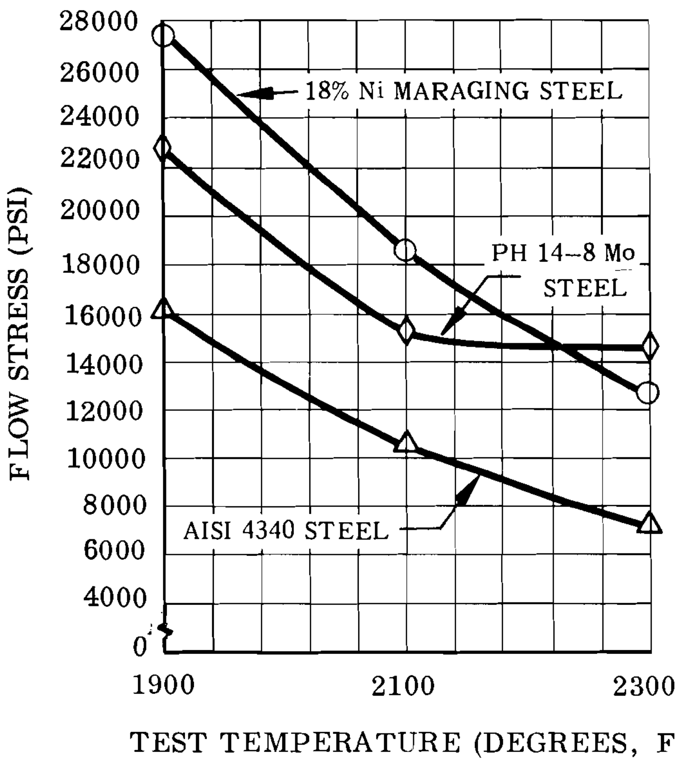


FIGURE 12. HOT DUCTILITY GLEEBLE DATA: FLOW STRESS VS TEST TEMPERATURE AT 6-SEC^{-1} STRAIN RATE

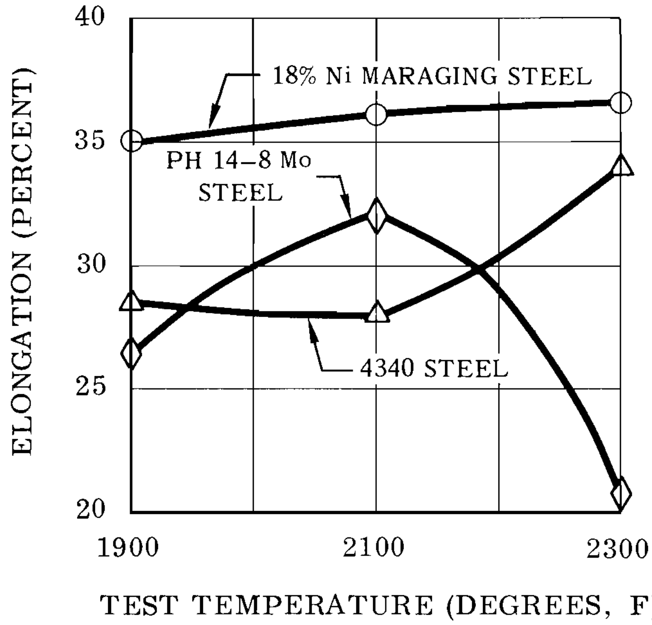


FIGURE 13. HOT DUCTILITY GLEEBLE DATA: ELONGATION VS TEST TEMPERATURE FOR 1-SEC^{-1} STRAIN RATE

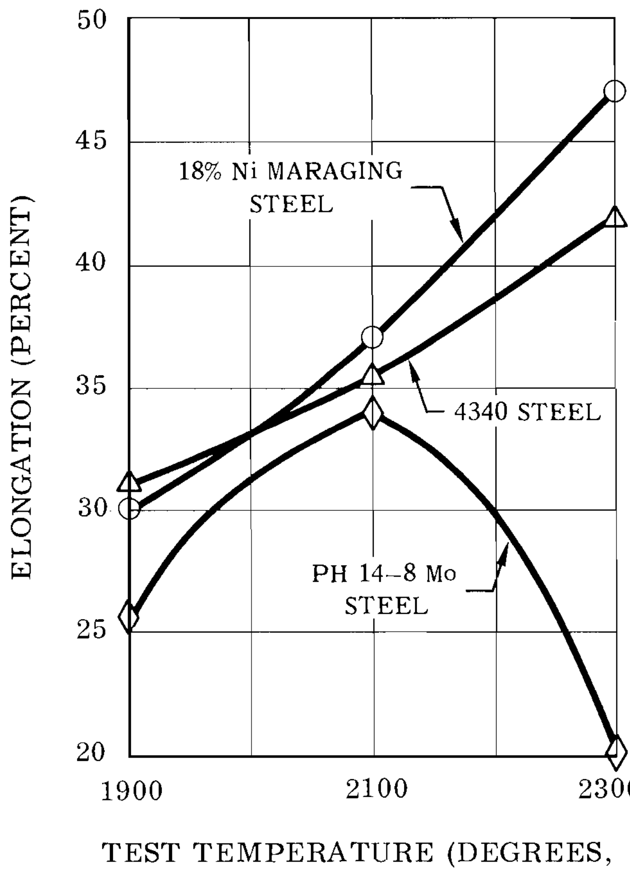


FIGURE 14. HOT DUCTILITY GLEEBLE DATA: ELONGATION VS TEST TEMPERATURE FOR 6-SEC^{-1} STRAIN RATE

PH 14-8 is both temperature- and strain-rate-sensitive. A 33-percent reduction in flow stress is possible at 6-sec^{-1} strain rate by increasing the temperature from 1900 to 2100F. The data show that the flow stress of PH 14-8 Mo is much lower at 2100F than at 1900F, while only a slight decrease in flow stress is noted by increasing the temperature to 2300F. A similar temperature sensitivity is shown at 1-sec^{-1}.

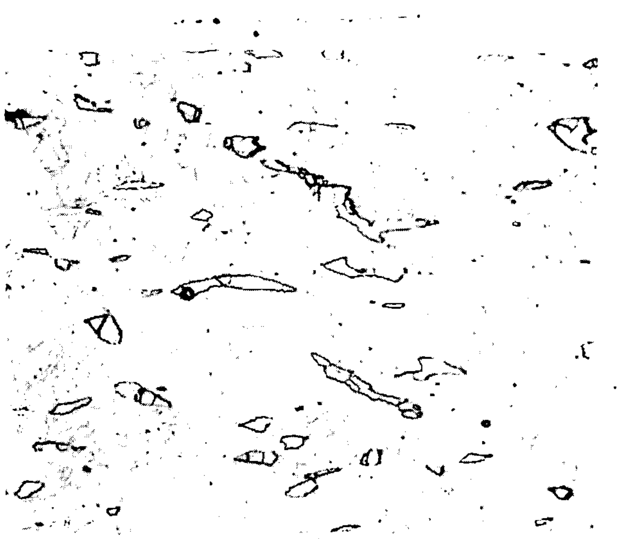
The elongation of PH 14-8 Mo shows little difference between 1-sec^{-1} and 6-sec^{-1} strain rates for all three temperatures tested. The data, however, show a drastic reduction in elongation between 2100 and 2300F. Two mechanisms are proposed as possible explanations for the observed behavior; however, it was not possible to define the exact nature of the responsible reaction.

(1) Grain-Boundary Precipitation Reaction

If the solubility of some phase or mixture of phases exhibits a sharp increase in the 2100-2300F range, then the redistribution of this phase or mixture of phases is responsible for the loss in ductility. That is, upon heating, the offending microconstituent dissolves in the matrix at elevated temperatures and reappears as a precipitate occurring preferentially at the grain boundaries. For example, the chromium carbide phase disappears at temperatures somewhat below the melting point, and it is possible that this phase is a contributing factor in the loss of ductility in PH 14-8 Mo.

(2) Incipient Melting

Another mechanism possible for the loss in ductility is incipient melting at the grain boundaries. If a low melting point phase exists in PH 14-8 Mo as a discontinuous network at the grain boundary, then incipient melting can occur. Depending on the amount, distribution, and solubility of the low melting phase, a discontinuous network of a low melting phase could grow into a continuous low-strength network. This hypothesis then would explain the loss of ductility because the strength of the entire boundary region would be low in the vicinity of low melting constituents. Photomicrographs of PH 14-8 Mo specimens after Gleeble testing at 2100 and 2300F are shown in Figure 15.



Tested at 2100F

Tested at 2300F

FIGURE 15. PHOTOMICROGRAPHS (250X, KALLINGS ETCH) OF PH 14-8 Mo AFTER TESTING AT 2100 AND 2300F

b. Billet Temperature

Billet temperature is perhaps the single most important extrusion variable that requires control and is also the most difficult to control. Temperature is important because the flow stress, plasticity, and hot ductility, as well as resulting mechanical properties, depend on temperature. Generally, billet temperatures used during the production of any extruded shape are not absolute values but are those established by experience of the press operator for each extrusion shape and alloy being extruded. This program has attempted to establish an absolute temperature requirement for the three alloys. This was not possible because of the difficulties in measuring and controlling the actual extrusion temperatures.

(1) Temperature Uniformity and Ray-O-Tube Accuracy

A special billet with four thermocouples was prepared to determine the accuracy of the Ray-O-Tube indicating temperature and the actual temperature uniformity within the billet. The surface of the test billet was ground free of any oxide so that the Ray-O-Tube temperature-sensing thermopile would give a constant reading. Three 0.25-inch holes were drilled through the diameter of the billet for the thermocouples. Chromel-Alumel thermocouple wires were inserted in the holes and cemented in place. The thermocouple wires were attached to a multichannel recorder to record the billet temperatures. The test billet was charged into a four-inch-diameter magnethermic heating coil heated to 2100F (as measured by the Ray-O-Tube) and held at temperature for five minutes. The billet was discharged and the temperature within the billet noted. The temperature uniformity within the billet was excellent, with less than 30F deviation between the surface and the center of the billet. The accuracy of the Ray-O-Tube, however, was less than seven percent of any one of the readings. The test was re-run using an optical pyrometer to check the temperature. This temperature measuring procedure proved to be no better than ten percent of the temperatures recorded by the thermocouples within the billet. These results meant that the temperatures controlled by the Ray-O-Tube are subject to about seven percent error of the desired temperature setting on the controller. Therefore, the billet temperatures reported for the extrusion of steel are not absolute values, but are those indicated by the Ray-O-Tube thermopile at the time the billet is ejected from the furnace.

The AISI 4340 billet temperatures investigated (as measured at the furnace by the Ray-O-Tube) were: 2200F, 2150F, 2120F, 2100F, 2050F, 2030F, 2000F, and 1950F. The billet temperatures investigated in establishing an extrusion process for PH 14-8 Mo were: 2250F, 2200F, 2175F, 2150F, 2100F, 2075F, 2050F, 2025F, 2000F, and 1975F. 18% Ni maraging steel billet temperatures were: 2000F, 2025F, 2050F, 2075F, 2090F, 2100F, 2125F, 2150F, 2175F, 2200F, and 2250F.

(2) Billet Heat Loss During Transfer Time

The temperature of the billet at the time of ejection from the furnace and the actual extrusion temperature is dependent on the transfer time and the heat losses due to melting of the lubrication glasses on the billet surfaces. To determine the rate of heat loss during transfer time, a billet was prepared with four thermocouples imbedded in the billet at various depths and one welded to the billet surface. The billet was heated to 2100F and held at temperature until all five thermocouple readings were within 10 degrees of one another. The billet was removed from the furnace and the temperature loss was recorded as a function of time. The results of the billet heat loss and the location of the thermocouples on the test billet are shown in Figure 16. The results show that after 10 seconds in still air, the temperature on the billet surface dropped about 140F and the temperature in the center of the billet dropped about 60F.

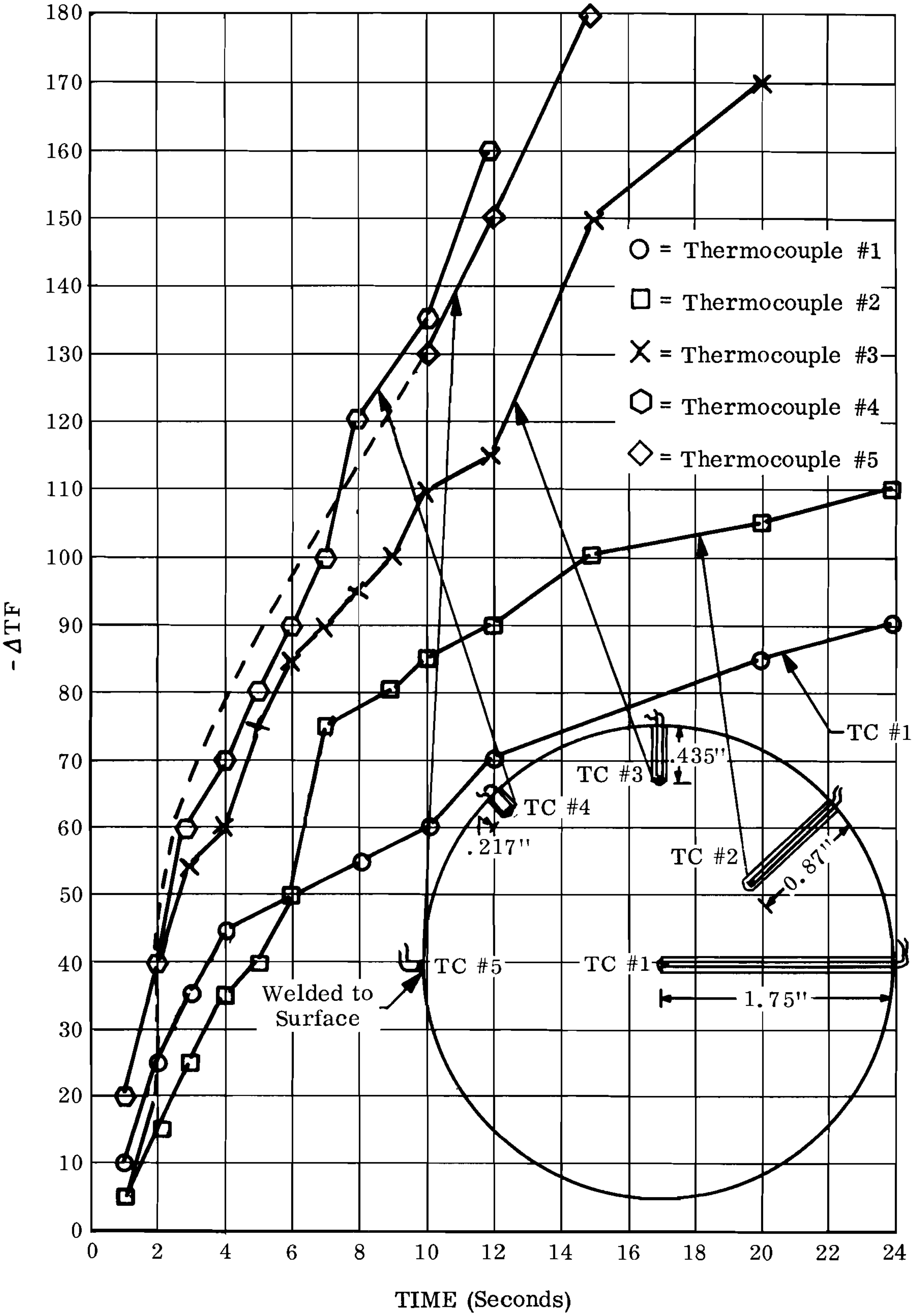


FIGURE 16. LOSS OF TEMPERATURE AS A FUNCTION OF TIME AT VARIOUS LOCATIONS IN A 3.5-INCH BILLET AT INITIAL TEMPERATURE OF T = 2100F

c. Exit Temperatures

A Ray-O-Tube type temperature-sensing unit was mounted 27 inches away from the back side of the extrusion die, and exit temperatures were recorded. The temperature of the extruded tee section was always higher than the estimated starting extrusion temperature. (Extrusion temperature is not to be confused with billet temperature. The temperature losses and inaccuracies in measurement make it impossible to specify an extrusion temperature. However, knowing the billet temperature is within ±7 percent plus the heat lost from the billet during transfer provides a reasonable estimate of the actual extrusion temperature. Assuming 2100F as a billet temperature and a 15-second transfer time, then the estimated extrusion temperature is 1850F.) Attempts to correlate the exit temperature data with billet temperatures, extrusion defects, or microstructure were not successful. Excellent defect-free extrusions in all three alloys were produced with exit temperatures in excess of 2300F. Other extrusions with 2300F exit temperatures were badly torn or defective. The microstructures of AISI 4340 with different billet and exit temperatures are shown in Figure 17. All the microstructures are a fine acicular untempered martensite typical of AISI 4340.

The average exit temperatures, however, decrease as a function of increasing flow stress, as determined by Gleeble testing. Figures 11 and 12 showed that flow stress at 2100F test temperature increases with increasing alloy content, i.e., AISI 4340 to PH 14-8 Mo to 18% Ni maraging steel. Table VI presents the exit temperature and flow stress data for the three alloys.

TABLE VI. AVERAGE EXIT TEMPERATURES AND FLOW STRESS FOR AISI 4340, PH 14-8 Mo, AND 18% Ni MARAGING STEEL

Alloy	Alloy Content (%)	Exit Temperature (F)	Flow Stress at 2100F and 1-sec^{-1} (psi)
AISI 4340	4.0	2160	9,000
PH 14-8 Mo	26.5	2120	12,000
18% Ni maraging steel	30.5	2090	13,200

4. POST-EXTRUSION THERMAL AND MECHANICAL PROPERTY TESTS

a. Tensile Testing

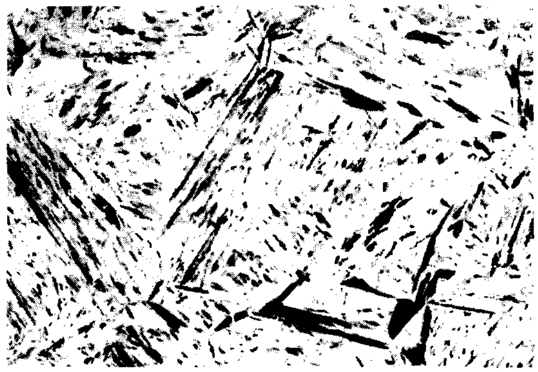
The purpose of conducting tensile tests was to determine the strength level of AISI 4340 in the as-extruded condition; to establish the proper AISI 4340 condition prior to stretcher straightening; and to determine the heat treat response of the AISI 4340, 18% Ni maraging steel, and PH 14-8 Mo extruded material. Fifty tensile specimens were prepared and tested to establish these data.

(1) AISI 4340

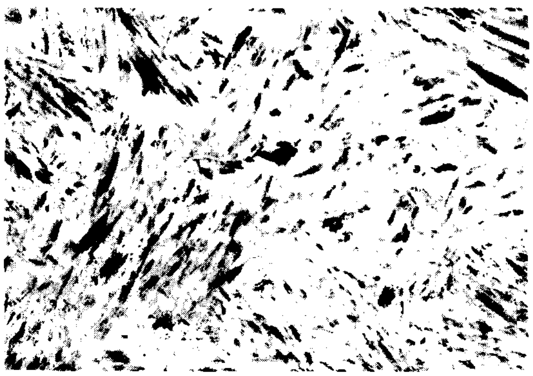
Table VII presents the tensile test results of AISI 4340 in various heat treated conditions. The as-extruded average tensile ultimate strength and elongation are 286.4 ksi and four percent, respectively. This strength level and ductility is typical of AISI 4340 untempered martensite.

250 X NITAL ETCH

Extrusion No. 26B
Billet T=2050F, Exit T=2120F

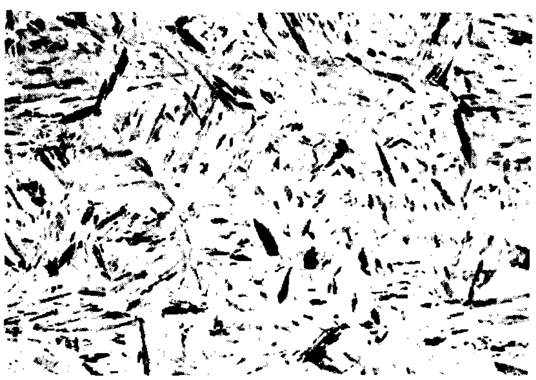


Extrusion No. 28B
Billet T=2050F, Exit T=2230F



Extrusion No. 21B
Billet T=2150F, Exit T=2300F

Extrusion No. 22B
Billet T=2150F, Exit T=2300F



Extrusion No. 27B
Billet T=2030F, Exit T=2090F

Extrusion No. 20B
Billet T=2200F, Exit T=2265F

FIGURE 17. PHOTOMICROGRAPHS OF AS-EXTRUDED AISI 4340 WITH BILLET AND EXIT TEMPERATURES NOTED

Before the extrusions could be straightened, the very brittle martensite had to be tempered to increase the elongation from 4 percent to approximately 20 percent. Several conditioning treatments were investigated prior to arriving at a conditioning treatment of:

Heat to 1225F in nitrogen atmosphere
Hold for two hours at temperature
Furnace cool to 900F
Air-cool to room temperature.

This tempering condition results in a fully tempered martensite with no presence of prior austenitic grain boundaries. The tensile ultimate strength and elongation of extruded material in the 1225F tempered condition are typically 119 ksi and 20 percent, respectively.

Three AISI 4340 tempering temperatures also were checked to gain assurance that the 260- to 280-ksi strength level contract requirement could be met. Because all AISI 4340 extrusions had to be straightened prior to Phase II drawing operations, the tensile specimens were first tempered at 1225F as discussed above, austenitized at 1525F for 20 minutes in an inert atmosphere, oil quenched, and tempered for two hours at three different temperatures of 350F, 400F, and 450F. The resulting strength and ductility levels of the three tempering temperatures are tabulated in Table VII. A tempering temperature of 350 or 400F results in the 260- to 280-ksi strength level.

(2) 18% Ni Maraging Steel

18% Ni maraging steel extruded material was tested in the as-extruded; extruded plus 900F age for three hours; and extruded plus solution treat at 1500F, air cool, and age at 900F for three hours. The test specimens were cut from four different extrusions to check for strength differences between extrusions as well as heat treat response. The strength levels of the extruded material in the above three conditions are presented in Table VIII. The as-extruded material is low in both strength and ductility. The material, however, responds very well to a 900F age for three hours, but is still much lower than the target yield strength and elongation level of 250 ksi and 12 percent, respectively. The average yield strength is only 210 ksi and elongation is 6.5 percent, or half the target 12 percent ductility level.

Tensile specimens were given the standard 1500F solution heat treat for one hour, air cool, and aged at 900F for three hours. The strength and ductility level of 18% Ni maraging steel after this thermal treatment should have met the target requirements. The average yield strength of the fully heat treated and aged material was, however, 32 ksi lower than the 250 ksi target. Only a very slight yield strength improvement of 8 ksi was noted over as-extruded and aged-only material with no ductility improvement.

The 6-8 percent ductility of as-extruded 18% Ni maraging steel was not adequate for stretcher straightening. Attempts to straighten the extrusions in various solution-annealed conditions were also unsuccessful. Additional heat treatment cycles were tested in an attempt to increase the ductility. These were:

(a) Single-anneal at 1150F for one hour and cool to room temperature (overaging). This treatment produced about 30-percent ductile austenite.

(b) Double-anneal at 1700F for one hour plus air cooling, followed by 1500F treatment for one hour plus air cooling. Specimens were prepared and solution-treated following the above schedules.

The average tensile test results were as follows:

TABLE VII. TENSILE TEST RESULTS OF AISI 4340 EXTRUSIONS IN VARIOUS HEAT TREATED CONDITIONS

Specimen No.	Condition	Yield Strength (ksi)	Ultimate Strength (ksi)	Percent Elongation In 1 Inch	Hardness (R_c, Av.)
40-4	As Extruded	172.6	282.4	4.5	---
43-2W	As Extruded	167.5	290.5	4.0*	51.5
40-1	1225F FC to 900F AC	92.8	114.8	19.0	---
42-1	1225F FC to 900F AC	90.6	117.4	22.0	---
43-1	1225F FC to 900F AC	92.4	115.5	22.0	---
48-1	1225F FC to 900F AC	98.0	121.2	20.0	
40-2W	1225F FC to 900F AC	92.7	118.5	20.0	23.5
42-2W	1225F FC to 900F AC	97.3	120.1	20.0	---
43-3	1225F FC to 900F AC	93.4	115.8	19.5	---
48-2W	1225F FC to 900F AC	81.0	111.5	20.0	---
40-3	1225F FC to 900F AC 1525F OQ 350F	208.7	286.0	10.0	54.0
42-3	1225F to 900F AC 1525F OQ 350F	206.3	278.7	13.0	52.2
43-4	1225F FC to 900F AC 1525F OQ 350F	213.5	283.9	12.0	52.6
48-3	1225F FC to 900F AC 1525F OQ 350F	213.9	278.2	11.0	51.6
40-5W	1225F FC to 900F AC 1525F OQ 400F	213.5	269.0	11.0	51.5
42-4	1225F FC to 900F AC 1525F OQ 400 F	198.2	262.2	11.0	49.8
43-5W	1225F FC to 900F AC 1525F OQ 400F	211.5	266.7	11.0	50.8
48-4	1225F FC to 900F AC 1525F OQ 400F	212.0	266.1	11.0	51.0
40-6	1225F FC to 900F AC 1525F OQ 450F	209.0	252.2	9.5	49.8
42-5W	1225F FC to 900F AC 1525F OQ 450F	205.2	248.7	9.5	48.6
43-6	1225F to 900F AC 1525F OQ 450F	204.7	250.0	9.5	49.2
48-6	1225F FC to 900F AC 1525F OQ 450F	203.0	246.4	9.5	47.6

* Broke outside gage mark

TABLE VIII. TENSILE TEST RESULTS OF 18% Ni MARAGING STEEL IN VARIOUS HEAT TREATED CONDITIONS

Specimen No.	Condition	Yield Strength (ksi)	Ultimate Strength (ksi)	Percent Elongation In 1 Inch	Hardness (R_c, Av.)
M-33-1	As-Extruded	115.9	143.8	7.5	34.5
M-33-2	As-Extruded	111.7	140.8	8.5	34.2
F-34-1	As-Extruded	112.1	144.8	8.5	33.5
M-44-1	As-Extruded	110.1	140.4	7.5	32.5
M-44-2W	As-Extruded	112.9	143.0	9.5	31.1
M-47-1	As-Extruded	110.5	143.6	9.5	32.9
M-47-2W	As-Extruded	111.1	141.3	9.5	31.5
	Average	111.5	142.0	8.5	- - -
M-33-3	900F Age for 3 hrs	207.2	222.5	6.0	51.0
M-33-4	900F Age for 3 hrs	209.7	225.5	6.0	49.6
F-34-3	900F Age for 3 hrs	217.3	237.4	7.0	49.2
M-44-5W	900F Age for 3 hrs	212.4	226.1	7.5	44.5
M-44-6	900F Age for 3 hrs	212.4	223.9	6.5	46.6
M-47-3	900F Age for 3 hrs	204.0	219.6	5.5	50.6
M-47-4	900F Age for 3 hrs	214.0	227.2	6.0	45.6
	Average	210.0	225.0	6.5	- - -
M-33-5	SHT 1500F AC 900F Age for 3 hrs	218.9	230.2	5.0	51.3
M-33-6	SHT 1500F AC 900F Age for 3 hrs	222.2	238.8	6.0	49.5
F-34-2	SHT 1500F AC 900F Age for 3 hrs	222.3	241.6	6.0	51.0
M-44-3	SHT 1500F AC 900F Age for 3 hrs	215.9	228.6	6.5	47.3
M-44-4	SHT 1500F AC 900F Age for 3 hrs	212.4	229.4	6.0	48.4
M-47-5W	SHT 1500F AC 900F Age for 3 hrs	219.4	229.4	7.0	47.3
M-47-6	SHT 1500F AC 900F Age for 3 hrs	219.2	227.7	6.0	51.0
	Average	218.0	232.0	6.0	- - -

Single Anneal

0.2% Yield Strength	=	127 ksi
Ultimate Tensile Strength	=	178 ksi
Elongation	=	16.7%

Double Anneal

0.2% Yield Strength	=	102 ksi
Ultimate Tensile Strength	=	133 ksi
Elongation	=	10%

The as-extruded ductility of maraging steel is typically 6-8 percent. The single anneal more than doubles the elongation and gives a much better yield-to-ultimate ratio than as-extruded material. Based on these results, maraging steel extrusions were given the 1150F overage treatment prior to stretcher straightening. Extrusions straightened without difficulty at 14 tons and 4 inches of stretch.

(3) PH 14-8 Mo

The tensile test results of PH 14-8 Mo material tested in the as-extruded and the SRH 950 condition are presented in Table IX. (SRH 950 condition is: solution anneal at 1825F for 3 minutes, austenitize at 1700F for 30 minutes, refrigerate at -100F for eight hours, age-harden at 950F for three hours.) The heat treat response of extruded PH 14-8 Mo was excellent. The SRH 950 thermal treatment resulted in properties higher than the target 175-ksi yield and 7-percent elongation.

TABLE IX. TENSILE TEST RESULTS OF AS-EXTRUDED AND HEAT TREATED PH 14-8 Mo EXTRUSIONS

Specimen No.	Condition	Yield Strength (ksi)	Ultimate Strength (ksi)	Percent Elongation In 1 Inch	Hardness (R_c, Av.)
52-5	As-extruded	104.7	157.3	12.0	40.5
52-9W	As-extruded	98.3	155.2	13.0	38.0
52-1	As-extruded	105.6	155.1	11.5	39.8
	Average	102.3	156.0	12.0	- - -
52-2	SRH 950	204.9	227.8	12.0	44.5
52-3	SRH 950	205.4	226.2	11.0	48.6
52-4	SRH 950	214.3	232.2	10.0	48.0
	Average	207.6	228.3	11.0	- - -

SECTION V

DRAWING PROCESS

The specific objective of the drawing phase was to develop a production process to reduce the thickness of tee extrusions produced in Phase I to a target thickness of 0.040 inch. One hundred fifteen extrusions were drawn in order to meet the thickness objective. The success of the drawing phase of this program is attributed to the invention of an adjustable draw die system that completely eliminates the necessity of "pointing." A patent will be applied for if the search of the prime art proves negative.

1. DRAW TEMPERATURE AND MATERIAL PLASTICITY

Drawing at room temperature is by far the most desirable approach for drawing any material. Drawing at elevated temperatures presents two major processing problems; temperature control and adequate lubrication. Both of these major processing problems are eliminated by drawing at room temperature . The primary reasons for drawing at elevated temperatures are to increase the plasticity of the metal and to reduce the rate of work hardening. If, however, the material being drawn has adequate plasticity at room temperature, and the rate of work hardening of the material is known, warm or hot drawing is not necessary. These material characteristics are known for annealed AISI 4340 and 18% Ni maraging steel. They are not known for PH 14-8 Mo; therefore, a series of room temperature mechanical tests was performed using extruded PH 14-8 Mo. Tensile specimens were machined from as-extruded material and tested to establish:

a. The relationship of hardness versus percent elongation for annealed and as-extruded material.

b. Work hardening characteristics (as measured by yield strength and hardness) of PH 14-8 Mo in the as-extruded and annealed condition.

c. The effect of loading rate on yield strength and hardness.

The relationship between hardness and percent elongation for annealed PH 14-8 Mo and as-extruded material was determined by loading one-inch gage length specimens in a tensile machine. A separable-type extensometer was attached to the specimens and load applied at 2 inches per minute and 0.2 inch per minute. After approximately 0.02 inch of plastic strain, the specimen was unloaded and hardness measurements taken in the reduced section. The loading-unloading procedure was repeated in 0.02-inch increments of plastic strain until failure. Hardness and elongation measurements were taken after each strain increment.

The results of the testing are presented in Figure 18. The Rockwell hardness of as-extruded PH 14-8 Mo material is about R_c 25 compared to R_b 75 for annealed material. The hardness of annealed material increases to R_c 20 after six-percent

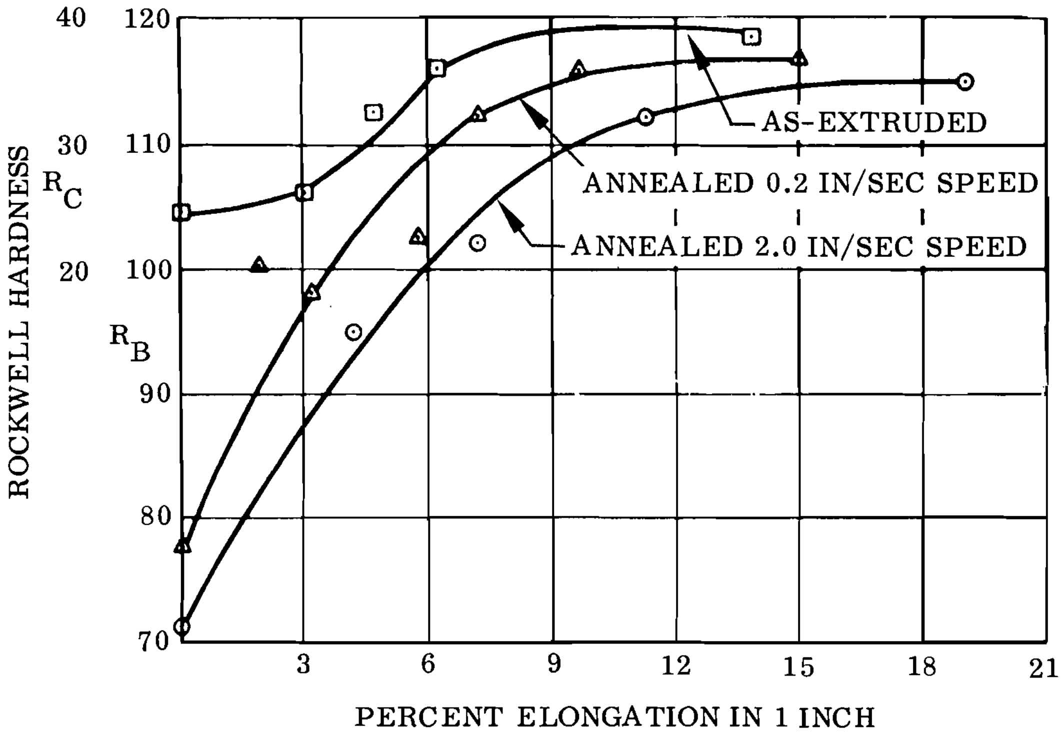


FIGURE 18. ELONGATION VERSUS HARDNESS INCREASE FOR PH 14-8 Mo IN AS-EXTRUDED AND ANNEALED CONDITIONS

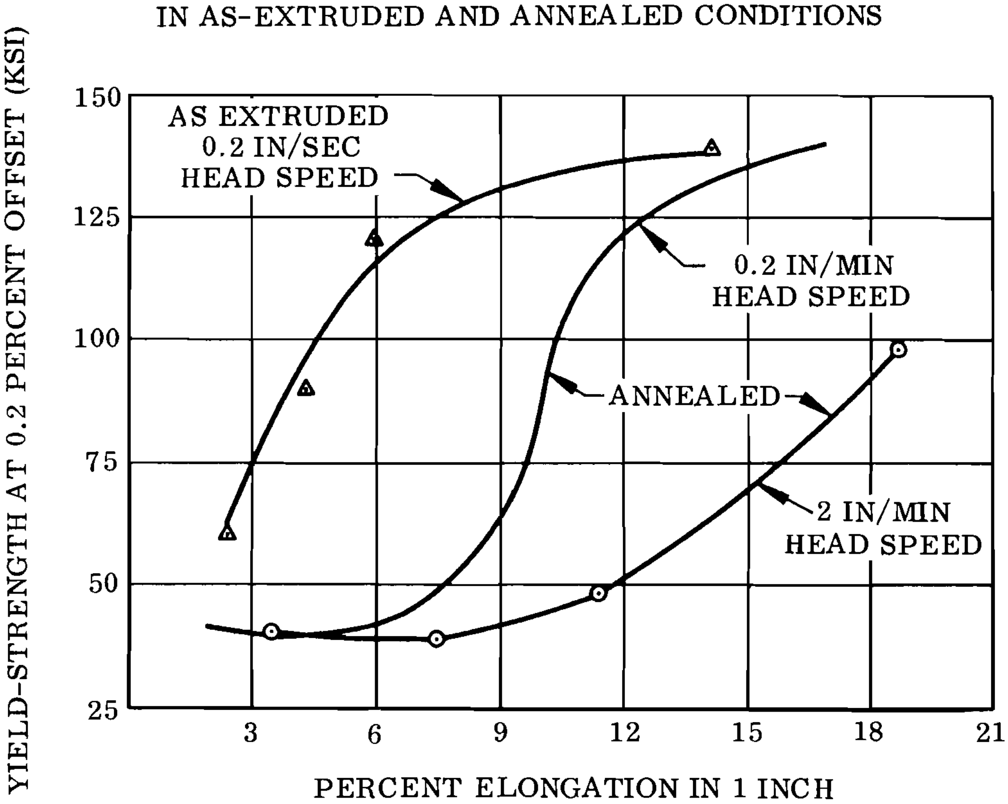


FIGURE 19. ELONGATION VERSUS YIELD STRENGTH FOR PH 14-8 Mo

total elongation, compared to R_C 36 for as-extruded material for the same amount of elongation. The hardness increases very little after nine-percent total elongation for both annealed and as-extruded material. The effect of loading rate (varied to simulate draw speeds) has an effect on hardness but does not appear to be significant.

Figure 19 presents a plot of yield strength at 0.2-percent offset versus elongation. In this test, yield strength is used as a measure of work hardening, and elongation as ductility. The increase in strength of annealed material is considerably lower than material in the as-extruded condition. The rate of work hardening of annealed and as-extruded material at two loading speeds is apparent on the graph. Based on the results of Figures 18 and 19 and early drawing experience with PH 14-8 Mo, a Rockwell hardness of R_C 30 was established as the criterion for re-anneal between passes through the die. These simple laboratory tests confirmed that drawing at elevated temperatures was not necessary. The low work-hardening coefficient of annealed AISI 4340 and 18% Ni maraging steel precluded performing the mechanical test described above for PH 14-8 Mo.

2. DRAWING LUBRICANTS

Lubricants evaluated during the drawing process development work included oils, graphites, disulfides, and conversion coatings used in conjunction with soap or "Teflon." Additional types of lubricants were scheduled for evaluation but were dropped because satisfactory lubricants for drawing the three alloys were established. The lubricant for room temperature drawing of PH 14-8 Mo extrusions is a conversion coating ("Bonderite 70") plus "Teflon" or soap. The conversion coating plus the surface lubricant effectively prevent any metal pickup on the die and eliminate die chattering (stick-slip). The liquid "Teflon" is applied with a cloth and dried at room temperature. It is very important that the "Teflon" be dry and free of any moisture. Experience has shown that only very slight amounts of moisture on the extrusion surfaces will cause stick-slip; if the drawing operation is not stopped, the carbide die will be damaged. Dry soap is equally effective, provided the surfaces are moisture-free.

The drawing lubricant used for both maraging steel and AISI 4340 was a graphite-base paste (trade name "Fel-Pro C-300") in a light resin carrier; it was applied with a brush and wiped to a relatively even thickness with a cloth. The lubricant adheres very well to the surfaces of the extrusions. As with the conversion coating and "Teflon," it is very important that the graphite lubricant be allowed to dry prior to drawing, or stick-slip will occur and damage the draw die. The importance of a dry, moisture-free surface cannot be overemphasized. If the surfaces are dry, the lubricants will prevent any metal-to-metal contact, prevent damage to the die, and eliminate any metal pickup. A significant point about the graphite-base lubricant is its adherence to the surfaces of the extrusions before and after the draw. Because of its excellent adherence, the lubricant is not reapplied between passes. In addition, the lubricant forms a protective coating on the surfaces of the extrusions and helps reduce corrosion (rust) that would occur if left unprotected in normal plant atmospheres. A photograph of extruded tee sections before and after drawing down to the target 0.040-inch thickness is shown in Figure 20. The lubricant is removed easily by a light grit blast. Chemical removal was not possible.

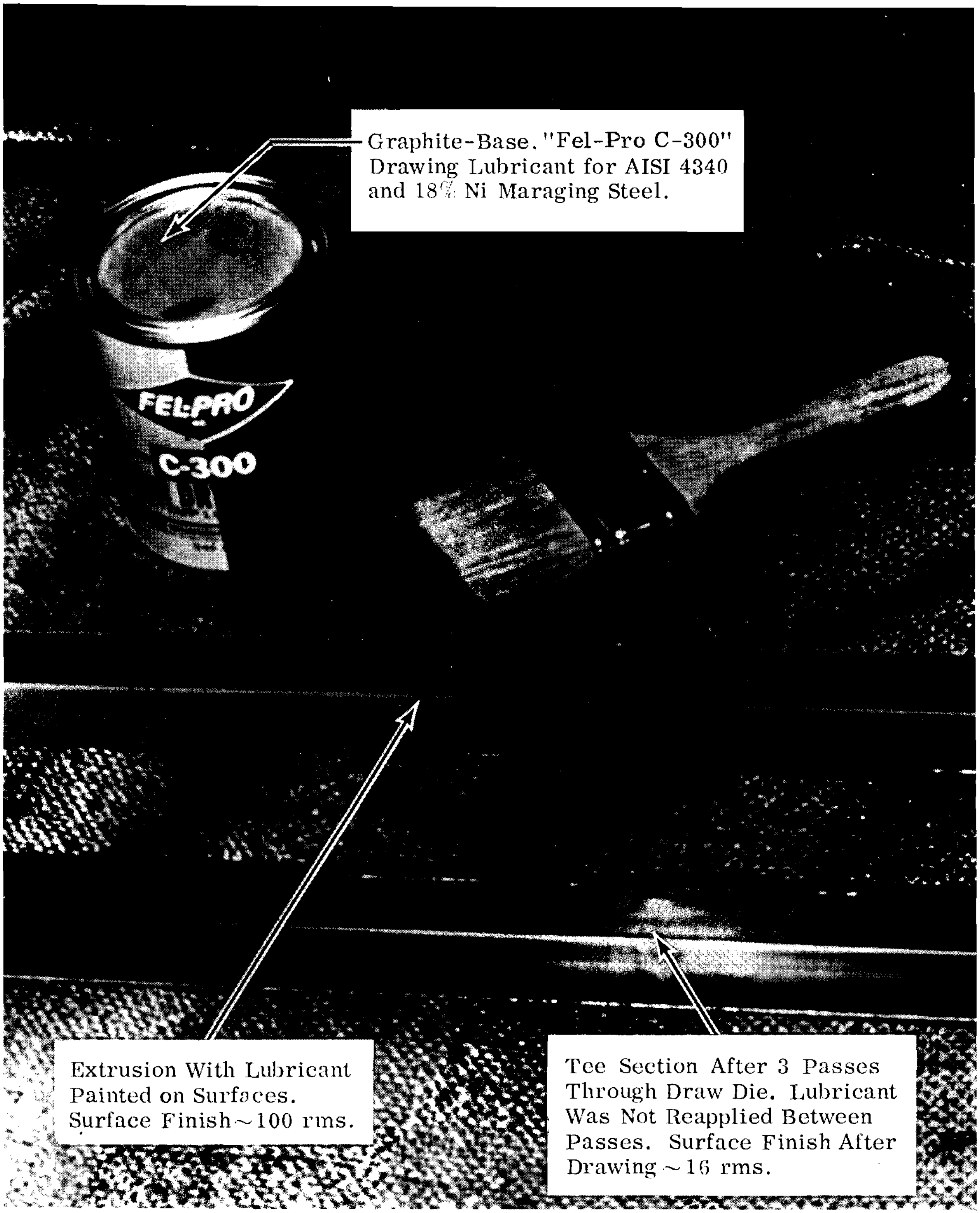


FIGURE 20. VIEW OF EXTRUSIONS BEFORE AND AFTER DRAWING

To determine if there was any diffusion of carbon from the graphite lubricant into the matrix of AISI 4340 and 18% Ni maraging steel, representative drawn tee shapes with the lubricant on the surfaces were sectioned, mounted, polished, and examined at 500- and 100-diameters magnifications. Meticulous examination of the surface areas and microhardness traverse did not show any carbonization or carbon diffusion into the matrix that could cause an undesirable chemistry balance.

3. DRAW DIE MATERIAL

The only die material used in this program was tungsten carbide with a nominal composition of 13-percent cobalt and 87-percent tunsten. The hardness of the material was R_a 88.

4. DRAW SPEED

The draw bench speeds tried during drawing trials ranged from four to ten feet per minute. The speed that produced consistently good surface finish was four feet per minute for all three alloys. Speeds faster than four feet per minute can cause severe rippling and not allow enough time to stop the draw bench if the extrusion stick-slips in the die.

5. POINTING

The first step in conventional drawing procedures is to "point" the shape to be drawn. "Pointing" means that the first six to eight inches of the extrusion are reduced in thickness to allow them to pass through the draw die. The pointed area then is pushed through the die and gripped by Hufford gripper jaws. The carriage which holds the gripper jaws is pulled down the draw bench. Deformation starts at the shoulder of the pointed area on the extrusion and continues the entire length of the extrusion. Pointing is normally a forge operation for rounds or simple-shaped extrusions. Extruded shapes such as tees, zees, and I's are pointed by chemical milling or push pointing. Both of these pointing processes are time consuming, expensive, and have the common problem of point failure soon after the drawing operation is started. The early drawing development work during this program was no exception to the point failure problem.

The first group of extrusions to be drawn was pointed by chemical milling in a 10-gallon solution of: 37% water, 32% H_3PO_4, 15% HCl, 17% HNO_3, 0.2% "Nacconal," and 4 grams of iron dissolved in the HCl per liter of solution. The solution was heated to 140F in a polyethylene container in a water double-boiler. The chemical reaction was violent and the fumes were noxious; therefore, the pointing was done in a well-ventilated area with a large fan adjacent to the acid container. The points of the extrusions were chemically milled thin enough to pass through a 0.045-inch die setting.

The thickness reduction per pass was established by inserting shims between the segmented carbide draw die. The reduction per pass on the first pass through the die was always set at the nominal thickness of the extruded shape. The die then was tightened and the die case cover plate installed. The die case was dropped in the draw bench retainer slot and the gripper head moved up to the exit side of the die. The thin pointed area was pushed through the die and the Hufford gripper jaws closed on the extrusion. The first pass through the die for all of the pointed extrusions resulted in less than two percent reduction in thickness. The draw die was reset to reduce the

thickness 0.005 inch. The points on 12 of the first 27 extrusions failed during the initial thickness-reduction pass and had to be re-pointed. The points on extrusions that were successfully drawn on the first pass through the die failed either on the second or third thickness reduction. These very discouraging results made it apparent that if a production drawing process was to be developed, the industry-accepted pointing operation had to be eliminated.

6. ADJUSTABLE DRAW DIE

An adjustable draw die was invented to eliminate the costly and time consuming pointing operation. The system is simple and practicable. The die and die-case arrangement is such that tapered wedges force the die segments onto the extrusion surfaces by turning four bolts. The die then upsets the material to a predetermined thickness. A photograph of the die and the adjustable bolts is presented in Figure 21. Figure 22 is a detail drawing of the adjustable thin draw die case, dies and inserts. The procedure developed in using the adjustable draw die is to: (1) open the draw-die case and loosen the adjusting bolts, (2) insert the extrusion, (3) close the die case with the cover plate, (4) grip the extrusion with the Hufford gripper head and pre-tighten the die adjusting bolts, (5) draw about four inches of extrusion through the die, (6) stop the draw and adjust the bolts to the to the desired thickness, and (7) draw the extrusion. In addition to eliminating the cost, time consumption, and handling problems associated with the "pointing" operation, a "back-drawing" procedure was developed that allows backward-and-forward drawing. This procedure is summarized as follows: After the first reduction, (1) the drawbench is stopped, leaving about six inches of stock, (2) the gripper head is released, (3) the die case is raised out of the drawbench, (4) the drawn tee is turned end-for-end and the die case lowered back into the holding slots of the bench, (5) the tail stock is gripped with the Hufford jaws and the adjusting bolts are tightened to a new thickness, and (6) the extrusion is drawn. The backward-and-forward procedure eliminates the necessity of re-inserting the estrusion and taking the die case cover plate off between passes. The backward-and-forward procedure is repeated until the thickness is a nominal 0.040 inch.

The procedure described above is most applicable to AISI 4340 and 18% Ni maraging steel. PH 14-8 Mo has a much higher work-hardening coefficient and requires an annealing thermal treatment between passes when the hardness exceeds R_c 30.

7. DRAWING RESULTS ANALYSIS

All drawing trails performed during this contract were aimed at establishing a reproducible procedure for drawing 20-foot-long extrusions to meet the target 0.040-inch thickness. The recorded information included thickness and length before and after the draw, lubricants, draw speeds, die settings, heat-treat conditions, and hardness of PH 14-8 Mo before and after the draw. All drawing was performed successfully at room temperature. One hundred fifteen extrusions were drawn in developing a reproducible production practice for the three alloys under study. The total number of passes through the die was 302. The thickness reduction per pass ranged from 0.005 inch to 0.015 inch. Changes in length ranged from 2 to 78 inches. Table X presents the maximum, minimum, and average thickness reduction and length increase in percent for the three alloys under development. The data in Table X represent all thickness and length changes per pass measured during the drawing trials. The thicknesses were measured on the stem, two locations on the base of the tee, and at three locations along the length of the extrusion before and after the draw. The nine separate thickness measurements for each pass through the die were averaged and used to calculate the percentages

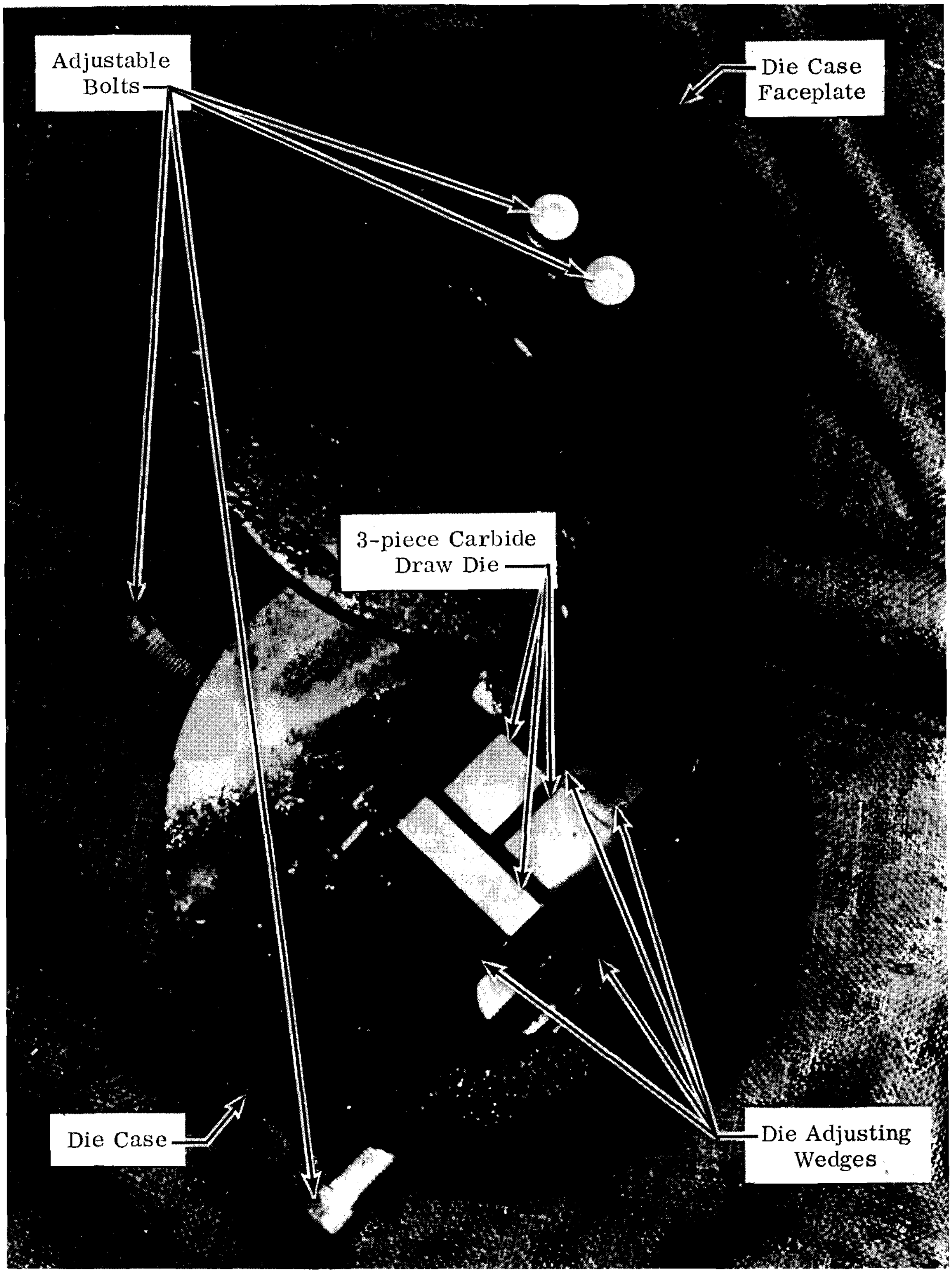
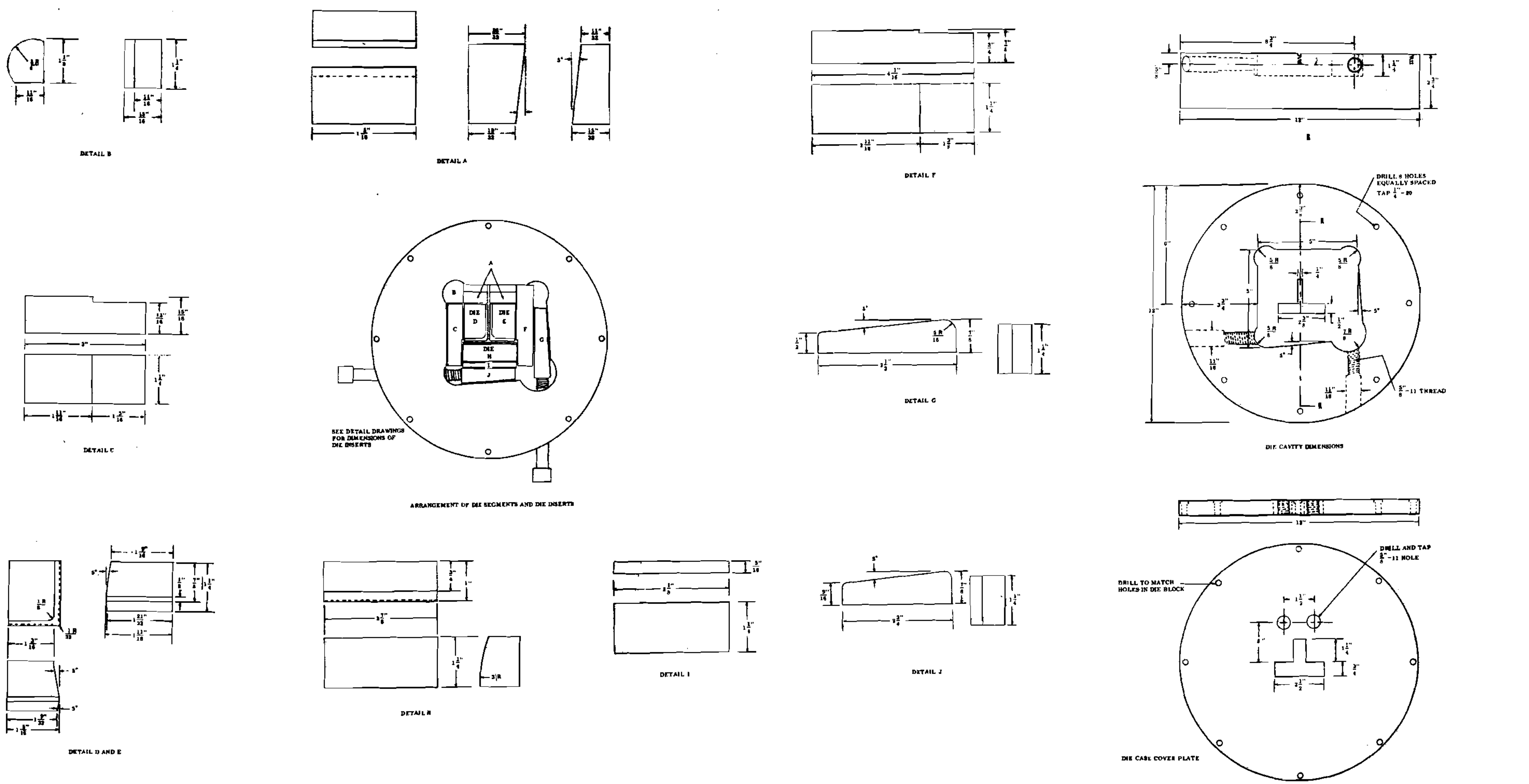


FIGURE 21. PHOTOGRAPH OF ADJUSTABLE DRAW DIE THAT ELIMINATES THE COSTLY AND TIME-CONSUMING "POINTING" OPERATION



ORIGINAL	T. LOOS
REDRAWN	D.J. NICHOLS
NORAIR APPROVAL	A.L. SCOW

A DIVISION OF NORTHROP CORPORATION, HAWTHORNE, CALIF.

FIGURE 21. ADJUSTABLE THIN TEE DRAW DIE

CODE IDENT NO. 76823

SCALE 2" = 1"

in Table X. The data presented in Table X represent 2,800 separate thickness measurements. The maximum differences in thicknesses between the base and stem of the tee averaged 0.0074 inch before the draw and 0.0039 inch after the final draw.

TABLE X. MAXIMUM, MINIMUM, AND AVERAGE THICKNESS REDUCTION AND LENGTH INCREASE PER PASS FOR THE THREE ALLOYS UNDER DEVELOPMENT

Alloy	Maximum Reduction (%)	Minimum Reduction (%)	Average Reduction (%)	Maximum Length Increase (%)	Minimum Length Increase (%)	Average Length Increase (%)
PH 14-8 Mo	27.27	3.6	12.9	31.0	1.7	9.26
18% Ni Maraging	13.7	1.6	8.7	11.5	0.8	6.38
AISI 4340	15.25	9.1	11.4	22.7	7.9	11.40

A significant point about the data reported in Table X is that the percent reductions per pass on all three alloys equals the reductions per pass for conventional production operations. One difference between the procedures developed to date for the three alloy tee extrusions and normal production drawing is the number of passes through the die. Normal production drawing operations use only one pass through the draw die. PH 14-8 Mo tee extrusions required three passes through the die to meet the target 0.040-inch thickness. One PH 14-8 Mo extrusion (number 107), however, was drawn down to 0.040-inch thickness in one pass through the die. Maraging steel required more passes than PH 14-8 Mo. Maraging steel extrusions were drawn down to target thicknesses in an average of four passes. The minimum number of passes for 18% Ni maraging steel was three. AISI 4340 extrusions met the 0.040-inch target in four passes through the die.

8. FINALIZED DRAWING PROCEDURES

a. PH 14-8 Mo

The procedure developed for drawing PH 14-8 Mo from the as-extruded thickness to the target 0.040 inches is as follows: (1) Apply a conversion coating ("Bonderite 70") and allow to dry completely. (2) Apply liquid "Teflon" or dry soap to the surfaces of the extrusion. (3) Set up the adjustable draw die to reduce the thickness per pass an average of 12 percent. (4) Draw the extrusions at four feet per minute. (5) Repeat the drawing procedure described in the drawing results section until the Rockwell hardness is R_c 30. (6) When the hardness reaches R_c 30, anneal at 1800F for five minutes and air cool. (7) Repeat the drawing-annealing cycle until the target thickness of 0.040 inch is reached. All drawing operations are carried out at room temperature.

b. AISI 4340 and 18% Ni Maraging Steel

Both AISI 4340 and 18% Ni maraging steel can be drawn to target thickness at room temperature without any inter-pass thermal treatments. The drawing of these two materials, however, was developed using a different lubricant than the conversion

coating. A graphite-base lubricant (trade name "Fel-Pro C-300") performed satisfactorily and did not require re-application between passes through the die. The thickness reductions and draw die process procedures for both AISI 4340 and 18% Ni maraging steel are the same as those described for PH 14-8 Mo.

9. STRETCHER-STRAIGHTENING OF DRAWN TEE SHAPES

Both AISI 4340 and PH 14-8 Mo extrusions were successfully stretcher-straightened without difficulty at room temperature after an annealing treatment. AISI 4340 was annealed at 1250F for one hour and furnace-cooled to 900F, followed by an air-cool to room temperature. The PH 14-8 Mo drawn shapes were annealed for five minutes at 1800F and air-cooled to room temperature. The stretcher straightening of both alloys was accomplished at room temperature.

The stretcher straightening of 18% Ni maraging steel is not as simple as AISI 4340 or PH 14-8 Mo. Stretcher-straightening of 18% Ni maraging drawn tee shapes was first tried in the extruded and as-drawn condition. However, the full-length drawn tee shapes broke in two at less than 0.5 inch of stretch. Mechanical property tests of the as-drawn material showed the ductility to be 3.7 percent. The 3.7 percent elongation was not adequate for stretcher-straightening. Laboratory tests were initiated to determine if the ductility could be increased after an overaging treatment of 1100F for one hour. This treatment produced more austenite in the matrix and increased the ductility from 3.7 percent to 11.0 percent.

Full-length extrusions were overaged at 1100F for one hour and stretcher-straightening was attempted. All of the extrusions broke during the stretch with little or no straightening. There are several explanations possible for the failure: (1) The tensile test data and conditions are not representative of the stretcher-straightening conditions; (2) 11.0 percent elongation is not enough ductility (the elongation of PH 14-8 Mo in condition A is 22.0 percent); (3) there are other characteristics of the drawn maraging steel that limit room temperature straightening.

Re-examination of extrusions that failed during straightening attempts indicated that the failures might have initiated at very small edge cracks. The tolerance for small edge cracks during room temperature stretcher-straightening is related to the material's strain hardening and notch sensitivity characteristics. The strain hardening coefficient of 18% Ni maraging steel was therefore determined and is compared with PH 14-8 Mo in Figure 23. The figure was developed from the power expression in the form $\sigma = K\epsilon^n$, where K is the stress at $\epsilon = 1.0$ and n, the strain-hardening coefficient, is the slope on the log-log plot of true stress versus true strain. The comparison shows that the strain hardening of 18% Ni maraging steel is an order of magnitude lower than that of PH 14-8 Mo. The low strain hardening of 18% Ni maraging steel is therefore a contributing factor in reducing the alloys stretcher-straightening characteristics.

The notch sensitivity of 18% Ni maraging steel also was determined. Tensile specimens were prepared and notched to produce stress concentration factors K_t of >20, 2.0, 1.4, and 1.0. A 0.050-inch square grid was printed on the specimens over a two-inch gage length and then the specimens were tensile-tested at room temperature. The data are plotted as percent elongation in 1.0 inch versus distance from the notch root to the edge of the specimen and are presented in Figure 24. Using elongation as a criterion, Figure 24 shows that the material is very notch-sensitive. Based on these results, all room temperature stretcher-straightening of 18% Ni maraging steel was discontinued.

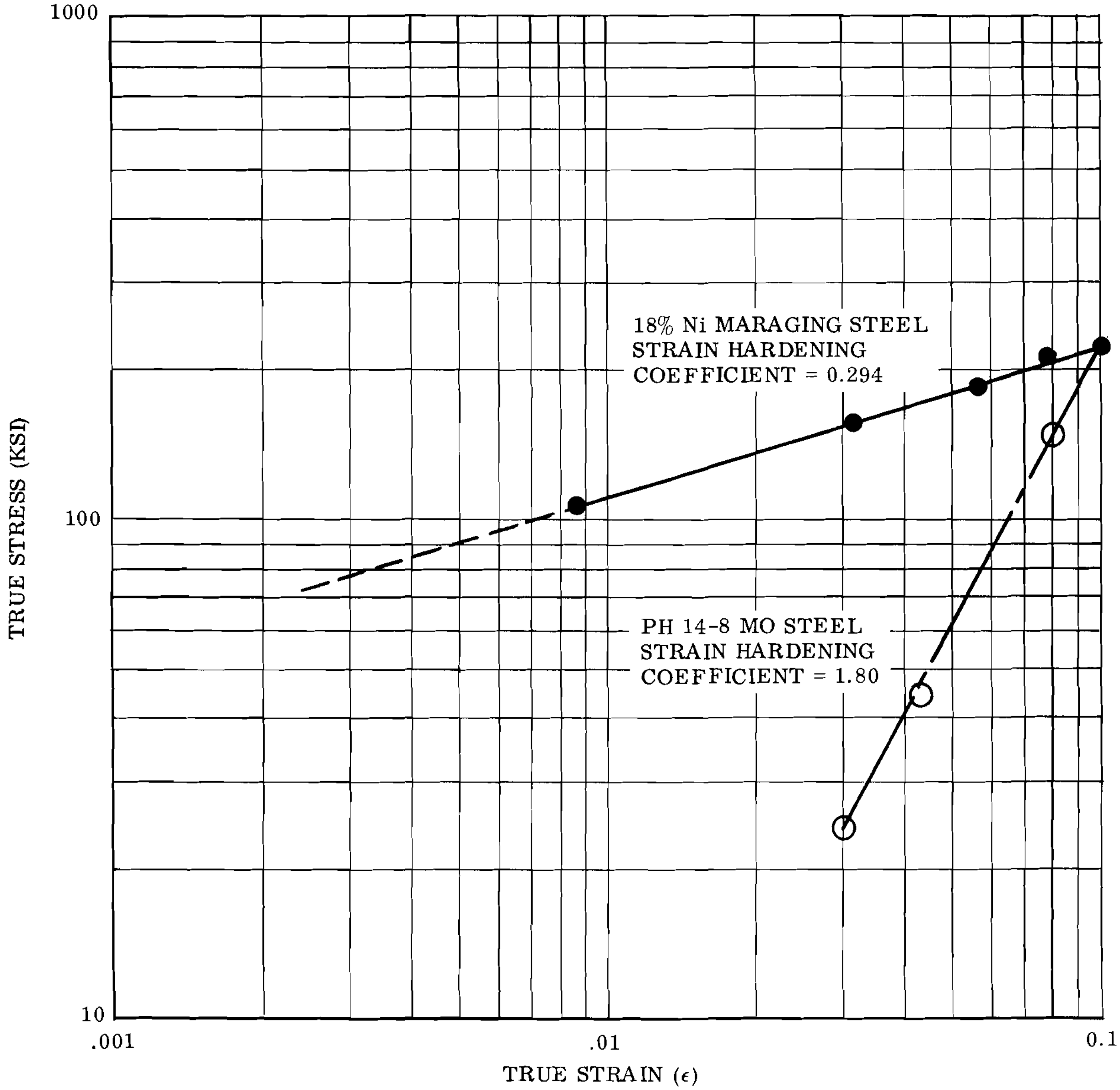


FIGURE 23. TRUE STRESS VERSUS TRUE STRAIN FOR 18% Ni MARAGING STEEL AND PH 14-8 Mo

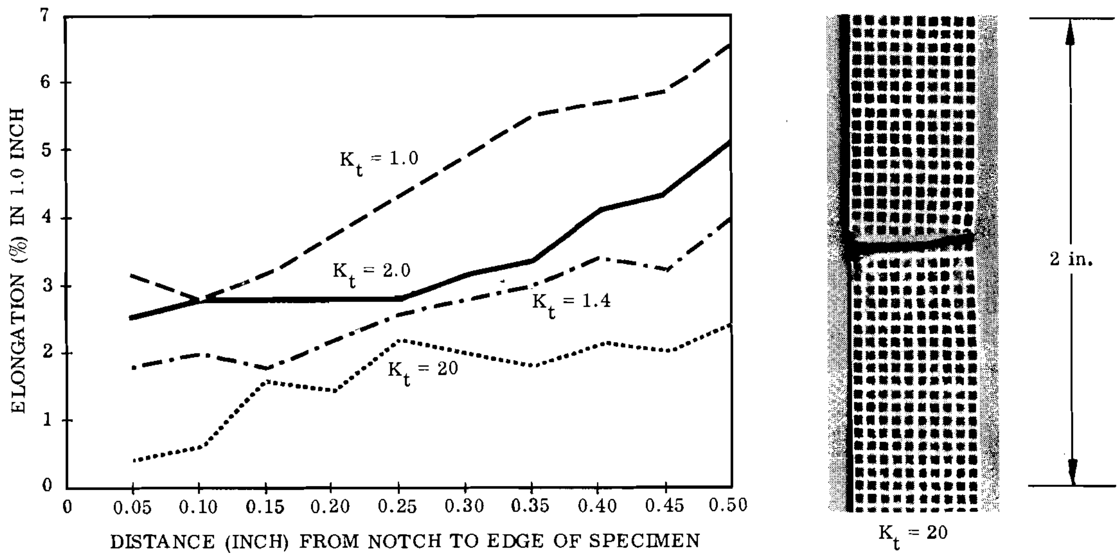


FIGURE 24. NOTCH SENSITIVITY OF 18% Ni MARAGING STEEL

Since stretcher-straightening at room temperature was not possible for reasons discussed above, "hot" stretcher-straightening was investigated using the Gleeble duplicator. Ten-inch-long specimens were prepared from 0.04-inch-thick drawn 18% Ni maraging steel for Gleeble testing. The specimens were tested at temperatures ranging from 1100 to 1500F and at loading rates ranging from 0.004 to 0.012 inch/second. The plasticity of the material was based on the maximum load the material could withstand before necking occurred. On the basis of these criteria, the temperature and the loading rate that resulted in the greatest amount of plasticity were 1100F and 0.004 inch per second. Full-length drawn 18% Ni maraging steel tee extrusions were gripped between Hufford jaws on the H. M. Harper Loma stretch straightener. The drawn tees were resistance-heated to 1100F, held at temperature for five minutes, and the load was applied at about 0.030 inch per minute. The extrusions were then routinely stretch-straightened.

SECTION VI

HEAT TREATING PROCESS

Phase III of this program was to optimize heat treatments to produce extruded and drawn tee sections to meet the mechanical properties and dimensional tolerances specified below:

Mechanical Properties (Longitudinal)

	AISI 4340	PH 14-8 Mo
Ultimate Strength (psi)	260,000	200,000
Yield Strength (psi)	217,000	175,000
Elongation	6%	7%

Dimensional Tolerances

Straightness of 0.003-inch per linear foot;
Twist of 1/4-inch per linear foot, 2 1/2 degrees maximum;
Flatness of 0.002-inch per inch crosswise dimension.

1. HEAT TREAT RESPONSE OF DRAWN AND STRAIGHTENED PH 14-8 Mo

As a part of Phase III activities, a series of tensile tests was first conducted on 0.040-inch-thick PH 14-8 Mo to determine the heat treat response of the drawn extrusions and to verify that the annealing and drawing cycles had not affected the material adversely. The heat-treat response tensile specimens were machined from extrusion number 93. The complete thermal and drawing history of the extrusion is as follows:

a. Extrusion Temperatures

Billet Temperature	2250F
Time to Reach Temperature	5 minutes 15 seconds
Time at Temperature	1 minute
Total Time in Furnace	6 minutes 15 seconds

Extrusion stretch-straightened at room temperature in "as-extruded" condition.

b. Drawing and Annealing Cycles

Extrusion thickness reduced 9.2 percent on first pass through the die; hardness increased 14 points.

Extrusion thickness reduced 22 percent in second pass through the die; hardness reached R_c 36 and the extrusion annealed at 1800F for 5 minutes.

Final pass through the die reduced the thickness 6.5 percent to an average thickness of 0.042 inch.

Extrusion annealed at 1800F minutes and stretch straightened at room temperature.

Five tensile specimens from the "as-drawn and straightened" extrusion described above were given the following SRH 950 heat treatment: (1) Solution anneal at 1825F for seven minutes and air cooled (Condition A); (2) austenite conditioning at 1700F for 15 minutes and air cooled (Condition A 1700); (3) cool within one hour after removal from the austenitizing treatment to -100F and hold at -100F for eight hours (Condition SR-100); and (4) age at 950F for one hour (Condition SR 950).

The tensile results of the drawn extrusions after the above heat treatment are listed below:

Specimen Number	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 1 inch)
93-1	197.3	231.0	10.5
93-2	199.7	223.6	10.5
93-3	204.0	224.6	9.5
93-4	201.8	227.1	14.0
93-5	206.5	227.7	14.0
Average	200.2	226.8	11.7

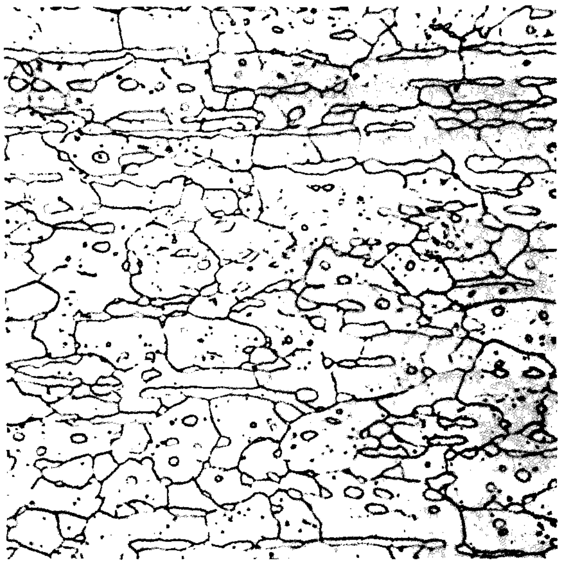
The above values are consistent with the properties of the extruded-only material; i.e., 205- to 214-ksi yield, 226- to 232-ksi ultimate, and 10- to 12-percent elongation. The values of both extruded and extruded and drawn PH 14-8 Mo after the SRH 950 heat treatment exceed the target values of 175-ksi yield, 200-ksi ultimate, and 7-percent elongation.

Four additional tensile specimens were tested and the microstructures examined after various stages of heat treatment. The tensile results of specimens after each heat-treat operation are tabulated below:

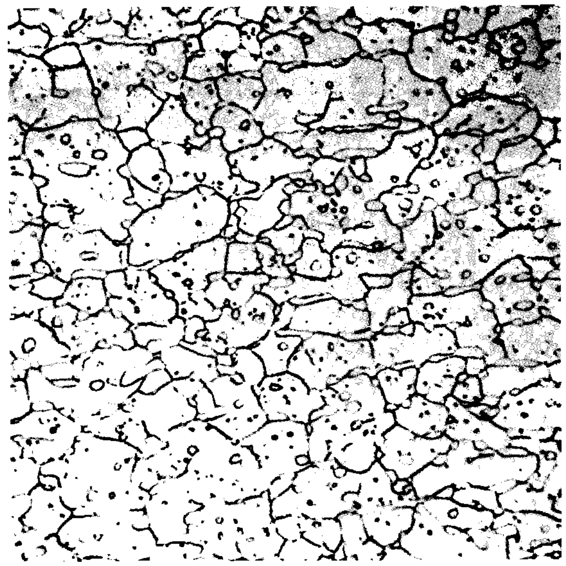
Specimen Number	Condition	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 1 inch)
93-6	A	44.7	136.8	22.0
93-14	A 1700	41.9	133.0	17.0
93-8	SR-100	128.7	173.5	14.0
93-10	SRH-950	201.3	226.4	13.5

The transverse and longitudinal microstructures of the material in each of the above conditions are presented in Figures 25 and 26. The microstructure of Condition A material consists of austenite and 10- to 11-percent delta ferrite. The austenitic grain size was estimated to be ASTM 9-1/2. The mechanical properties of 44.7 ksi

500X Nitric-Acetic, electrolytic and 10% Oxalic, electrolytic Etchants



Longitudinal

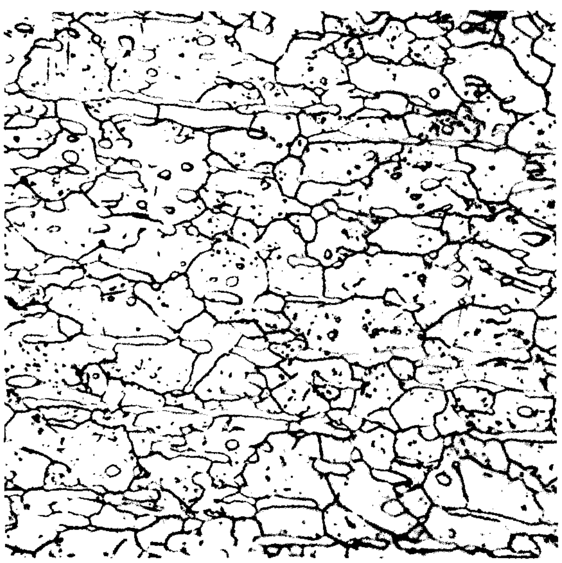


Transverse
(Ferrite content = 9.7%)

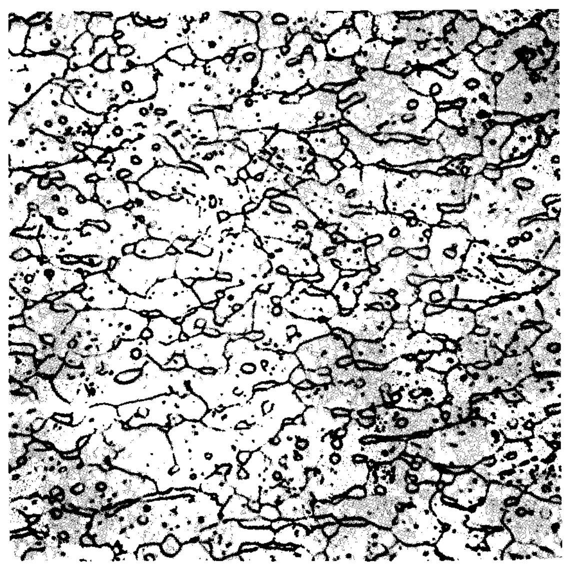
ASTM Grain Size No. = 9 1/2

Yield strength = 44.7 ksi, ultimate strength = 136.8 ksi, and elong. = 22%

Condition A



Longitudinal



Transverse
(Ferrite content = 10.7%)

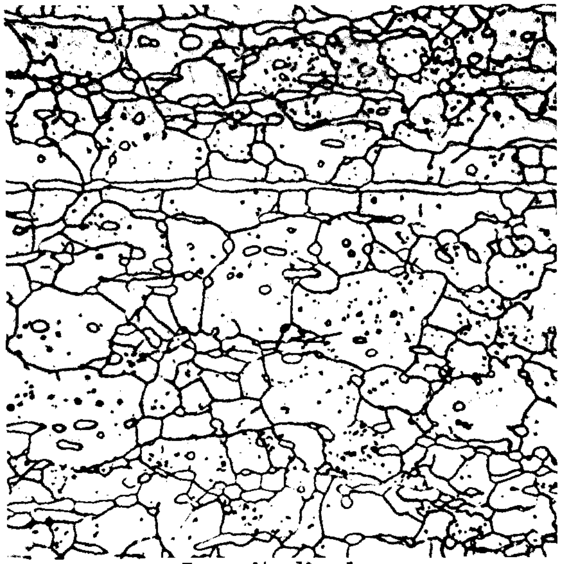
ASTM Grain Size No. = 9 1/2

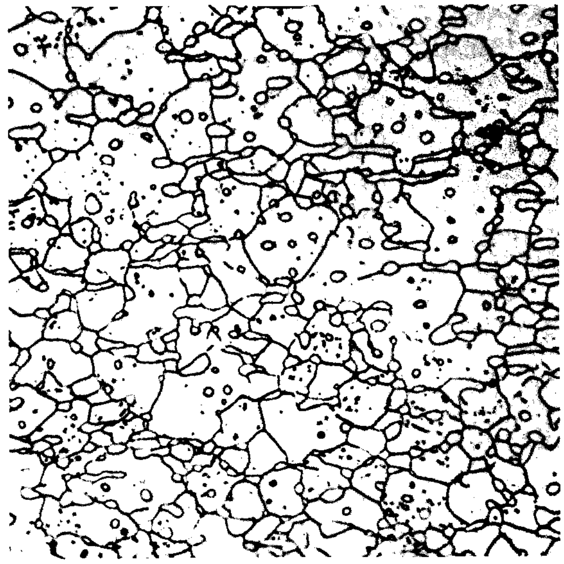
Yield strength = 41.9 ksi, ultimate strength = 133.0 ksi, and elong. = 17.0%

Condition A 1700

FIGURE 25. PHOTOMICROGRAPHS OF DRAWN AND HEAT TREATED PH 14-8 Mo EXTRUSIONS, CONDITION A AND CONDITION A 1700

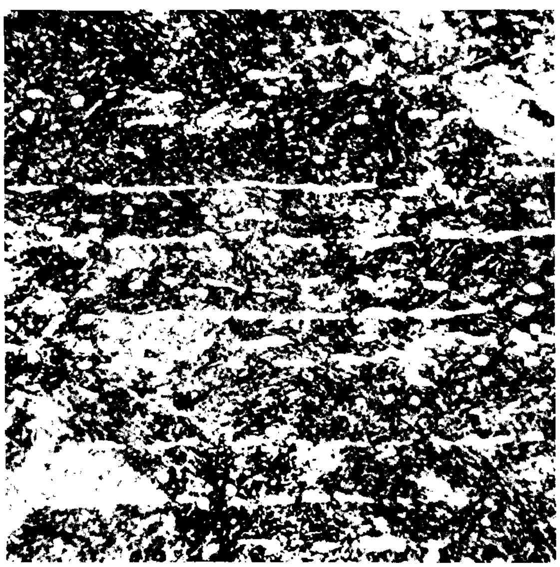
500X Nitric-Acetic, electrolytic and 10% Oxalic, electrolytic Etchants

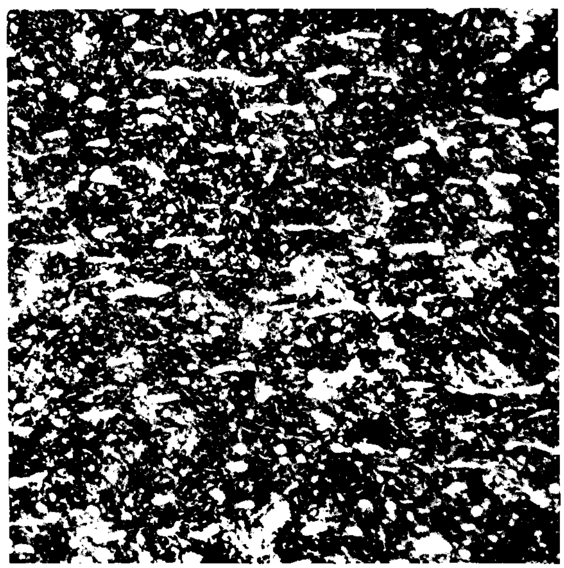

Longitudinal


Transverse
(Ferrite content = 10.8%)

ASTM Grain Size No. = 9 1/2

Yield strength = 128.7 ksi, Ultimate strength = 173.5 ksi, and elong. = 14.0%
Condition SR-100


Longitudinal


Transverse
(Ferrite content = 10.8%)

ASTM Grain Size No. = 9 1/2

Yield strength = 201.3 ksi, ultimate strength = 226.4 ksi, and elong. = 13.5%
Condition SRH 950

FIGURE 26. PHOTOMICROGRAPHS OF DRAWN AND HEAT TREATED PH 14-8 Mo EXTRUSIONS, CONDITION SR-100 AND CONDITION SRH 950

yield, 136.8-ksi ultimate, and 22-percent elongation for Condition A vary somewhat from the values published in the Armco PH 14-8 Mo handbook. Condition A values reported by Armco are: 55-ksi yield, 125-ksi ultimate, and 25-percent elongation. The microstructure of PH 14-8 Mo in the A 1700 condition is very similar to Condition A and consists of austenite and 10- to 11-percent delta ferrite. The mechanical properties of Condition A 1700 do not vary considerably from Condition A. The 15 minutes at 1700F did not cause any discernible grain growth. The austenitic grain size was estimated at ASTM 9-1/2. Transforming the austenite to martensite with the SR-100 treatment increased the strength of the material as expected. Yield strength is increased from 45-ksi to 129-ksi, and the ultimate strength is increased from 137- to 174-ksi. The microstructure consists of untempered martensite, retained austenite, and 10- to 11-percent delta ferrite. The microstructure of transformed material is very similar to Condition A 1700 because the etchant does not readily attack the untempered, low-carbon martensite. The austenitic grain size was estimated at ASTM 9-1/2. Aging at 950F for one hour precipitates a Ni-Al compound in the martensitic matrix and increases the strength of the material to its desired value. The tempered martensite is recognizable along with the delta ferrite in the microstructure. Retained austenite is also present in this condition, but has not lowered the aging response of the material. The mechanical properties and microstructure of the extruded-straightened-drawn-straightened material after the standard SRH 950 heat treatment shows that the target properties of 175-ksi yield, 200-ksi ultimate, and 7-percent elongation are exceeded.

2. HEAT TREAT RESPONSE OF DRAWN AND STRAIGHTENED AISI 4340

The first step in optimizing the heat treating conditions for AISI 4340 was to determine as-drawn and stretch-straightened properties and to establish the response of the material to heat treat times and temperatures. Table XI presents the as-drawn mechanical properties.

TABLE XI. MECHANICAL PROPERTIES OF EXTRUDED AND DRAWN AISI 4340

4340 Specimen Number	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 2 inches)
42 C-1	147.2	156.3	5.0
42 C-2	148.0	155.9	6.5
42 C-3	148.5	156.7	6.0
42 C-4	147.8	156.2	5.0
42 C-5	137.2	154.7	4.5
Average	145.7	155.9	5.4

The "standard" times and temperatures for AISI 4340 are as follows:

Solution anneal at 1500F for one hour and oil quench.
Temper in the range of 400 to 500F for two hours and air cool.
Solution anneal is performed under controlled atmosphere conditions.

The procedure followed for heat treating AISI 4340 specimens was to envelope them between 0.004-inch-thick sheets of 321 stainless steel, evacuate the envelope and

purge with argon gas for three cycles, and finally seal the envelope by resistance welding. The tensile specimens were heat treated following the above times and temperatures, and tensile tested. The results are reported in Table XII.

TABLE XII. MECHANICAL PROPERTIES OF AISI 4340 AFTER "STANDARD" HEAT TREATMENT

4340* Specimen Number	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 2 inches)
42 D-1	219.6	277.3	6.5
42 D-2	221.3	278.5	5.5
42 D-3	219.5	278.1	6.0
42 D-4	217.7	280.4	6.0
42 D-5	219.4	278.3	7.0
Average	219.5	278.5	6.2

*Tempering temperature was 400F

3. HEAT TREAT RESPONSE OF DRAWN AND STRAIGHTENED 18% Ni MARAGING STEEL

A series of tensile tests were first conducted on 0.040-inch-thick 18% Ni maraging steel tee material to determine the heat treat response and to verify that the 1100F stretch-straightening temperature had not affected the material adversely. Tensile specimens were machined from extrusions in the as-drawn, drawn, and hot-stretch-straightened conditions. The specimens were then tested and the results tabulated (Table XIII).

TABLE XIII. MECHANICAL PROPERTIES OF AS-DRAWN AND AS-STRETCH-STRAIGHTENED 18% Ni MARAGING STEEL

Specimen Number	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (% in 2 Inches)	Condition
142 C-1	158.8	159.8	3.5	As-Drawn
142 C-2	151.6	159.5	3.5	
142 C-3	158.4	160.3	4.0	
127 C-1	150.8	156.4	3.5	
127 C-2	153.4	158.7	4.0	
127 C-3	150.8	157.2	3.5	
Average	153.9	158.6	3.7	
124-21 B	178.0	184.0	8.5	As-Stretch-Straightened at 1100F
124-22 B	176.3	181.4	9.5	
124-23 T	168.4	178.2	11.5	
124-24 T	161.2	177.5	11.5	
124-25 B	181.0	187.0	5.5	
Average	172.9	181.6	9.3	

Tensile specimens machined from stretch-straightened material also were heat treated at 1500F for 30 minutes, air-cooled, and aged at 900F for three hours. This is the standard heat treat schedule for the 250-grade 18% Ni maraging steel; the results of this heat treat schedule are presented in Table XIV.

TABLE XIV. HEAT TREAT RESPONSE OF 18% Ni MARAGING STEEL EXTRUSION

Specimen Number	Yield Strength (psi 0.2% Offset)	Ultimate Strength (psi)	Elongation (% in 2 Inches)
124-26 B	253.0	257.4	2.5
124-27 B	249.3	252.7	2.5
124-28 B	249.0	253.4	2.5
124-29 T	244.0	247.5	2.5
124-30 T	248.5	251.5	2.5
124-31 B	254.3	257.3	2.5
124-32 B	248.7	250.2	2.0
124-33 B	247.0	254.0	2.5
124-34 B	246.2	246.7	2.0
124-35 T	248.7	251.3	2.5
Average	248.9	252.2	2.5

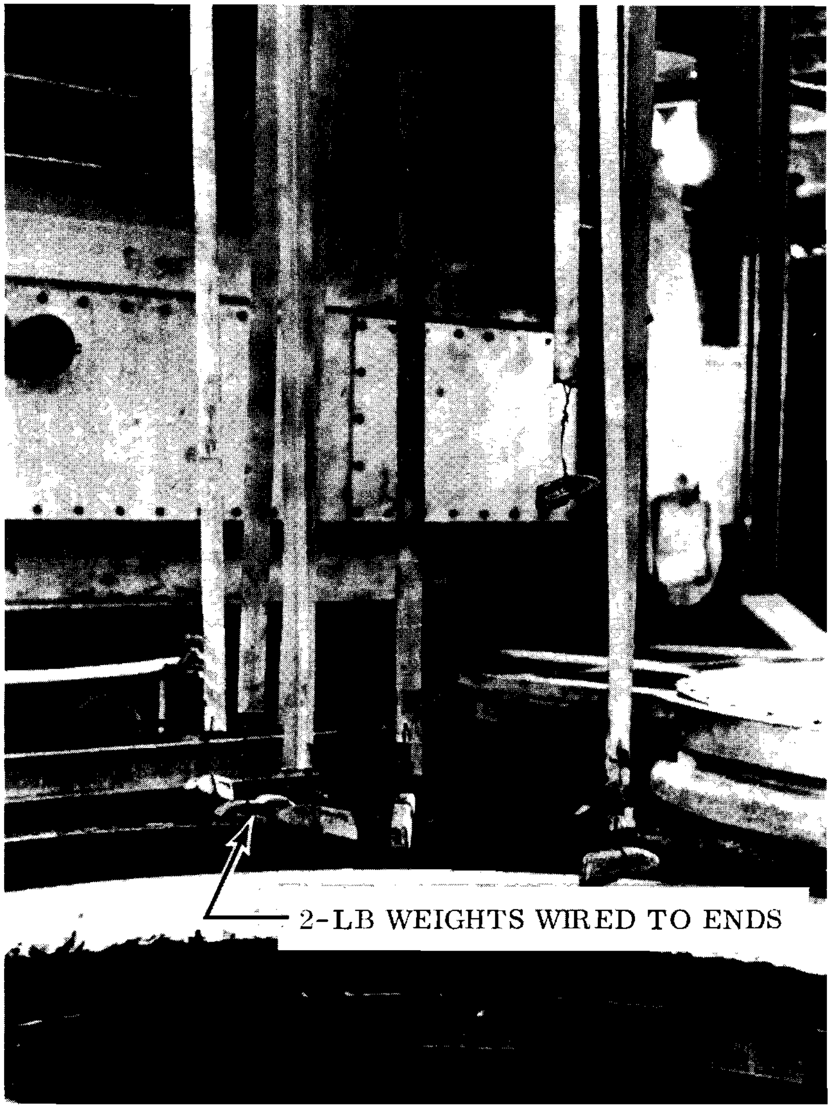
These properties are consistent with guaranteed minimum sheet properties for maraging steel; therefore it is concluded that the heat treat response is acceptable.

4. PRODUCTION HEAT TREATING PROCEDURES DEVELOPED AT LINDBERG STEEL TREATING COMPANY

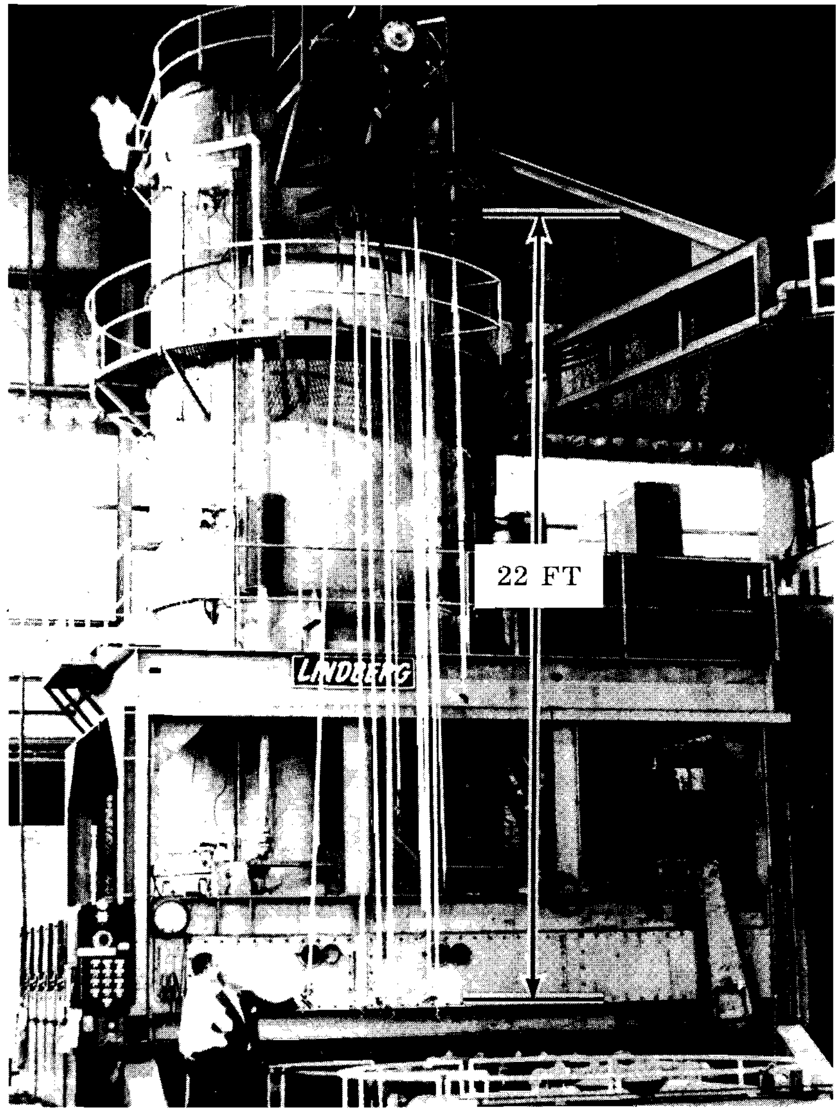
a. AISI 4340

The heat treat times and temperatures for strengthening AISI 4340 are well documented and substantiated by tests described in this report section. The objective of heat treating the extruded and drawn shapes was to establish a procedure to minimize distortion and maintain a 260- to 280-ksi strength level. The production heat treating procedures established for the 0.040-inch-thick by 20-foot-long extrusions are as follows: (1) Suspend the drawn shapes vertically and attach a two-pound counterweight to the end of each extrusion. (2) Pre-heat the tee shapes to 900F and hold for 15 minutes. (3) Austenitize the shapes at 1550F for 15 minutes; maintain dew point of the endothermic atmosphere at from +47 to +49F. (4) Quench in a neutral salt bath and hold for five minutes; remove from the salt and air-cool to room temperature.

Figure 27 is a photograph of the AISI 4340 extrusions before and after the austenitizing described above. The white color noticeable on the extrusion surfaces is due to the solidified neutral salt. Also shown is a photograph of the two-pound weights attached to the ends of the extrusions. Note the straightness of the shapes after the quench. The drawn extrusions were then washed in hot water to remove the salt. The tee shapes were then "snap" tempered at 325F for 30 minutes and cooled to room temperature before installing in a tempering fixture. The tempering fixture is shown in Figure 27. It was designed to reduce any distortion to an absolute minimum. The fixture was made of low alloy steel and can accommodate two drawn extrusions per tempering cycle. The fixture weighs an estimated 1500 pounds and is suspended vertically in the tempering furnace. The extrusions were tempered at 400F for two hours and air-cooled to room temperature.



View Showing Extrusions Before Quench.



View After Quench Showing Length and Straightness.

FIGURE 27. PHOTOGRAPHS OF ELEVEN AISI 4340 EXTRUSIONS BEFORE AND AFTER AUSTENITIZATION

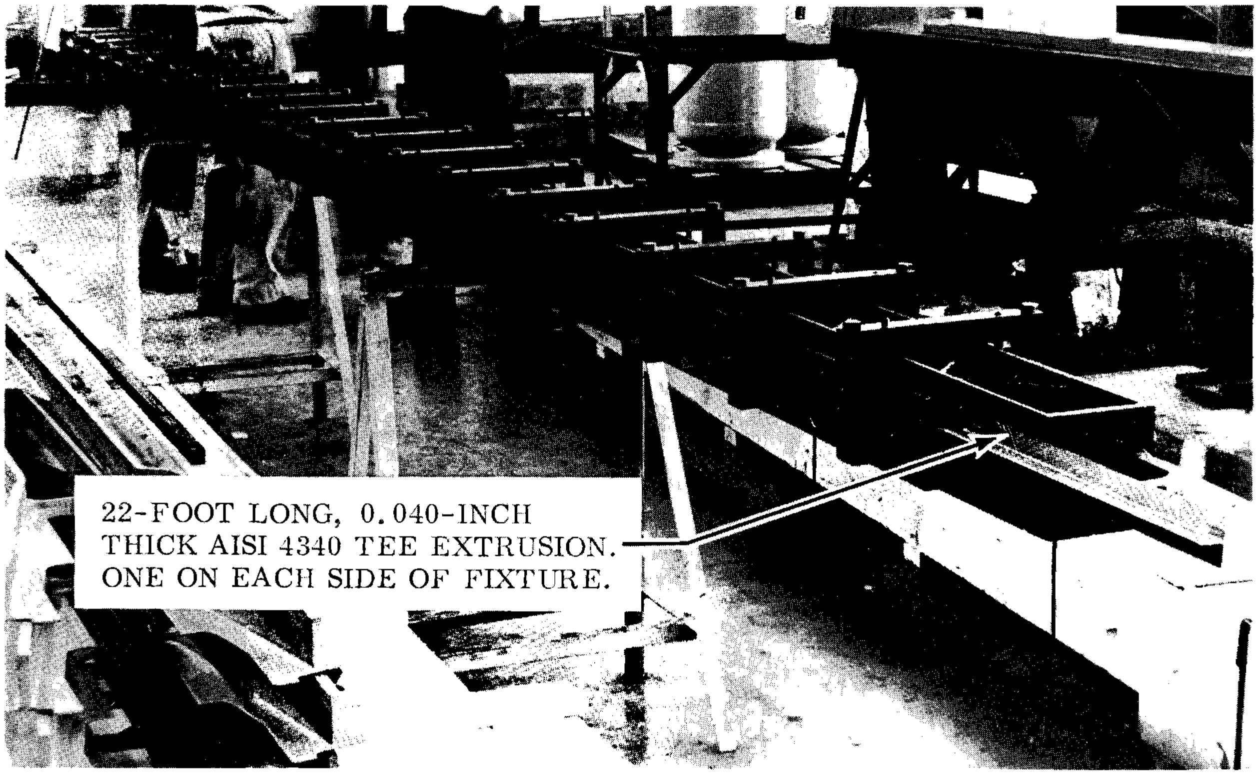


FIGURE 28. PHOTOGRAPH OF TEE EXTRUSIONS IN TEMPERING FIXTURE

A photograph of some heat treated, extruded, and drawn 0.040-inch-thick tee shapes is shown in Figure 29.

b. PH 14-8 Mo

The details of heat-treat sequence for strengthening PH 14-8 Mo are as follows: (1) Solution anneal at 1825F for seven minutes and air-cool. (2) The extrusions then are austenitized at 1700F for 15 minutes and air-cooled. (The microstructures of the solution anneal, Condition A, and the austenitization, Condition A 1700, were shown in Figure 24. The drawn PH 14-8 Mo tee shapes also were suspended vertically with a two-pound weight attached to assist in straightening any distortion that may not have been removed during the stretcher-straightening operation.) (3) The extrusions are transformed to martensite by holding at -100F for eight hours in a specially designed transformation chamber described in the equipment section of this report. The transformed drawn tee shapes are precipitation hardened at 950F for one hour in the same tempering fixture as was shown in Figure 27.

c. 18% Ni Maraging Steel

The production heat treat schedule established for 18% Ni maraging steel is as follows: (1) Vertically suspend the drawn tee shapes and attach a 1-3/4-pound weight on the end of each extrusion. (2) Load the furnace (see page 11 for a complete description of the furnace) and hold at 1550 ± 10F for 30 minutes. (3) Air-quench to room temperature. (4) Fixture the solution annealed tee shapes in the jig as shown in Figure 28. For temperature sensing, attach a thermocouple rather than the normal air thermocouple to the fixturing jig. Load the fixture in a 900F preheated furnace and age the extrusions

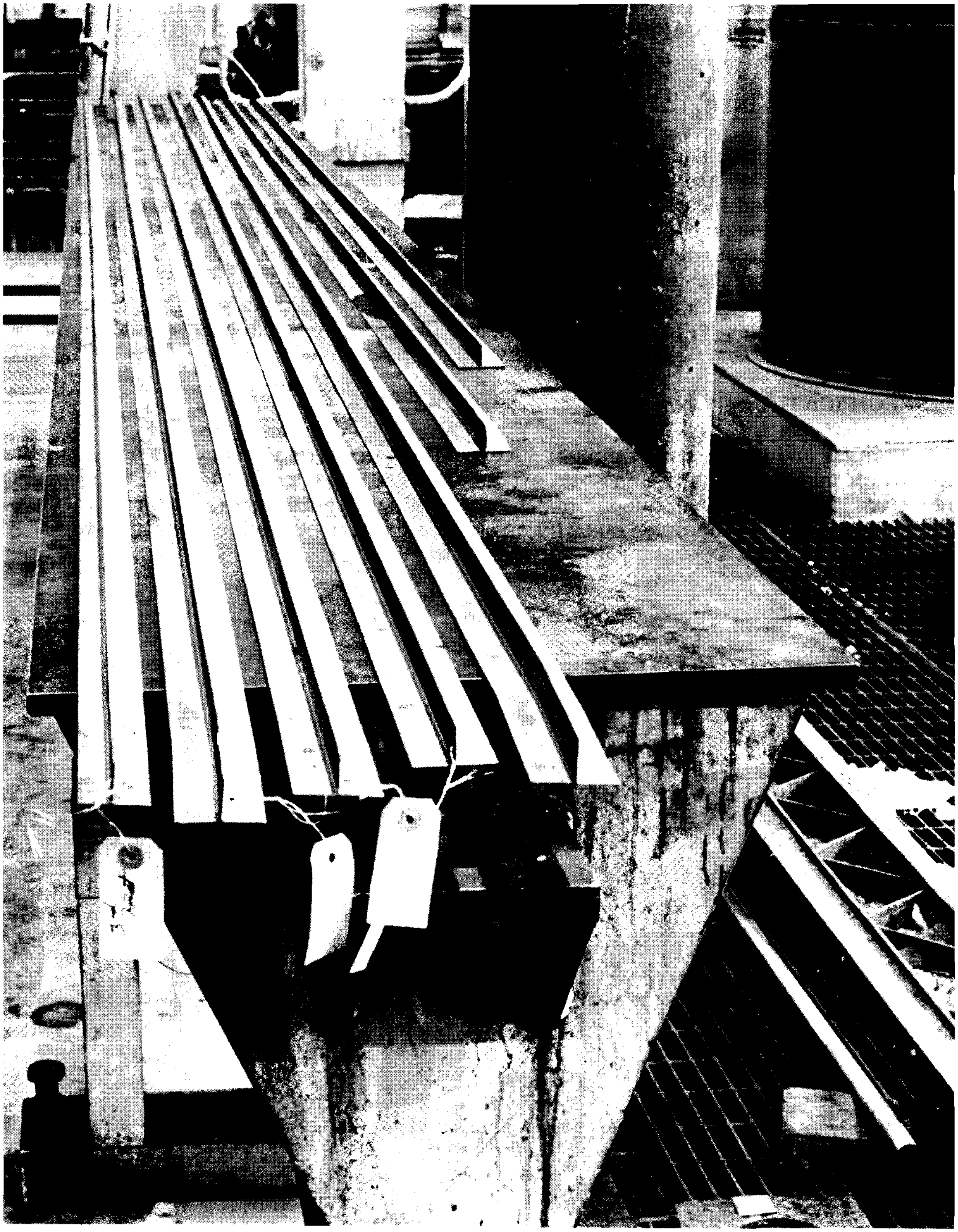


FIGURE 29. PHOTOGRAPH OF HEAT TREATED (260-280 KSI) AISI 4340 EXTRUDED AND DRAWN TEE SHAPES SHOWING STRAIGHTNESS AND LENGTH

for three hours after the fixturing jig has reached the aging temperature. (5) Air-cool the extrusions in the fixture to room temperature. (6) Dimensionally inspect the extrusions.

5. DIMENSIONAL INSPECTION AND SURFACE ROUGHNESS MEASUREMENTS

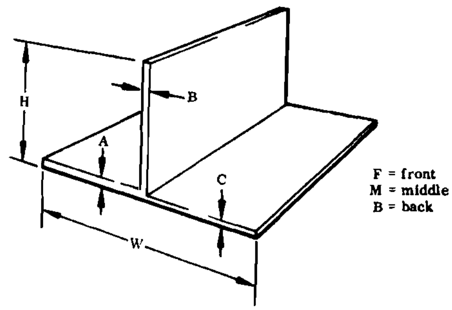
Dimensional inspection and surface roughness measurements for extruded, drawn, and heat treated AISI 4340 are presented in Table XV. The table is self-explanatory and defines the areas and locations for the thickness, height, and width measurements. In addition, surface roughness measurements were obtained by using Brush Surfindicator Model BL-110. The surface roughness measurements are much better than the target RMS of 60. The roughness measurements reported in Table XV were taken at two locations on the extrusion and represent a range of three separate readings on the Surfindicator. Tables XVI and XVII are identical records for extruded, drawn, and heat treated PH 14-8 Mo and 18% Ni maraging steel respectively.

6. SPECIFICATIONS

Appendices II and III present complete specifications prepared to serve as a reasonable standard of manufacture for thin steel extrusions of AISI 4340 and PH 14-8 Mo alloys, respectively. The documents contain a list of applicable documents, material requirements, dimensional properties, quality assurance provisions, and preparation for delivery requirements.

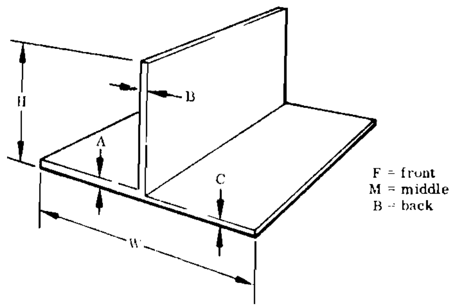
[illegible]

TABLE XV . DIMENSIONAL INSPECTION AND SURFACE ROUGHNESS MEASUREMENTS OF EXTENDED, DRAWN, AND HEAT TREATED AISI 4340 TEE SHAPES



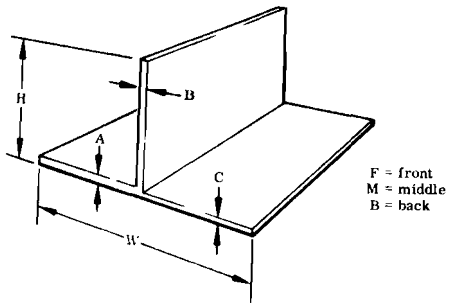
Stamped Extrusion No.	Length Feet		Thickness Inch A	Thickness Inch B	Thickness Inch C	Height Inch F	Height Inch B	Width Inches F	Width Inches B	Surface Roughness (RMS) F	Surface Roughness (RMS) B
6	19 1/4	F M B	.043 .043 .0435	.039 .038 .039	.045 .045 .046	0.89	0.89	1.92	1.94	16-18	21-23
11	21 1/2	F M B	.043 .042 .039	.0395 .038 .038	.039 .039 .039	0.91	0.91	1.88	1.91	21-23	17-19
13	21 2/3	F M B	.038 .0365 .038	.040 .0395 .040	.040 .0395 .041	0.88	0.86	1.56	1.44	26-28	24-28
22	21 1/2	F M B	.0415 .0435 .043	.046 .047 .047	.0415 .043 .043	0.89	0.88	1.91	1.91	21-23	21-24
24	21 3/4	F M B	.043 .0445 .045	.039 .041 .042	.039 .040 .045	0.94	0.92	1.89	1.91	21-23	21-25
33	21 5/6	F M B	.0395 .0385 .051	.042 .040 .056	.041 .0415 .050	0.89	0.87	1.86	1.86	28-32	27-30
32	21 1/2	F M B	.047 .038 .038	.066 .053 .055	.063 .051 .052	0.91	0.94	1.82	1.92	26-29	28-31
40	21 1/2	F M B	.043 .0425 .042	.039 .0385 .0385	.039 .0385 .039	0.94	0.92	1.94	1.91	18-23	19-22

TABLE XVI. DIMENSIONAL INSPECTION AND SURFACE ROUGHNESS MEASUREMENTS OF EXTENDED, DRAWN, AND HEAT TREATED PH 14-8 Mo TEE SHAPES



Stamped Extrusion No.	Length Feet		Thickness Inch			Height Inch		Width Inches		Surface Roughness (RMS)	
			A	B	C	F	B	F	B	F	B
83	16 1/2	F M B	.041 .041 .042	.035 .036 .036	.040 .041 .040	0.96	0.95	1.96	1.94	32-34	36-38
77	21 1/2	F M B	.042 .041 .038	.041 .041 .039	.041 .039 .038	0.95	0.95	1.91	1.94	28-30	30-34
87	19 3/4	F M B	.039 .039 .038	.041 .041 .041	.040 .039 .039	0.95	0.96	1.90	1.91	32-36	30-32
91	21 1/2	F M B	.040 .040 .039	.039 .039 .038	.040 .039 .038	0.96	0.95	1.96	1.95	34-36	34-34
94	21 1/2	F M B	.040 .040 .040	.039 .040 .039	.040 .039 .040	0.98	1.0	1.94	1.94	28-30	30-32
95	21 1/2	F M B	.040 .039 .039	.039 .038 .039	.041 .039 .040	0.95	0.96	1.99	1.98	28-30	36-38
96	14 1/2	F M B	.047 .047 .047	.042 .042 .042	.045 .047 .049	0.96	0.97	1.95	1.96	34-36	28-30
103	20 1/4	F M B	.041 .041 .041	.039 .039 .038	.041 .041 .041	0.96	0.95	1.96	1.95	30-32	34-36
107	21 1/2	F M B	.039 .038 .037	.037 .037 .037	.040 .039 .039	0.98	0.97	2.0	1.98	28-30	28-30
134	21 1/2	F M B	.037 .038 .037	.035 .035 .035	.037 .034 .034	0.97	0.96	1.98	1.97	24-28	21-24

TABLE XVII DIMENSIONAL INSPECTION AND SURFACE ROUGHNESS MEASUREMENTS OF EXTENDED, DRAWN, AND HEAT TREATED 18% Ni MARAGING STEEL



Stamped Extrusion No.	Length Feet		Thickness Inch			Height Inch		Width Inches		Surface Roughness (RMS)	
			A	B	C	F	B	F	B	F	B
8	23	F M B	.040 .040 .041	.042 .040 .042	.043 .042 .045	0.94	0.91	1.89	1.91	35-40	30-35
9	22 1/3	F M B	.042 .043 .042	.043 .044 .043	.048 .046 .046	0.88	0.86	1.82	1.92	42-45	45-49
7	22 1/2	F M B	.039 .038 .040	.045 .044 .046	.040 .040 .041	0.89	0.89	1.94	1.91	38-45	30-40
10	16 1/2	F M B	.046 .045 .041	.043 .043 .043	.047 .044 .042	0.98	1.0	1.96	1.95	40-45	30-40
6	16 1/3	F M B	.043 .040 .042	.040 .037 .042	.041 .039 .041	0.94	0.92	1.86	1.86	38-40	35-45
4	19 1/2	F M B	.033 .033 .034	.038 .036 .036	.052 .052 .052	0.91	0.91	1.94	1.94	28-35	30-35
1	19 5/6	F M B	.038 .044 .038	.038 .044 .038	.048 .049 .050	0.89	0.94	1.94	1.89	35-40	40-45
3	14 5/6	F M B	.048 .048 .047	.052 .049 .050	.046 .047 .046	0.91	0.91	1.56	1.44	48-50	45-48

SECTION VII

CONCLUSIONS

1. PHASE I, EXTRUSION PROCESS

a. Extrusion Operation

(1) This program has made available to the Air Force and industry thin steel extrusions. A reproducible manufacturing process for the extrusion of 0.062-inch-thick by 20-foot-long tee shapes in AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel was developed at the H. M. Harper Co. using a 1,200-ton Lowey-Hydropress.

(2) There is a relationship between alloy content and extrudibility. AISI 4340 is the easiest to extrude, 18% Ni maraging is the most difficult, and PH 14-8 Mo is between the two.

(3) The surfaces of all extrusions produced are essentially glass-free. Glass lubrication of the die bearing areas is apparently not critical in extruding thin steel tee sections. The glass lubricant is not carried through the die with the extrusion.

(4) The design of the glass pad between the billet and the die is important. The die-glass pads must not cover the die openings. The function of the glass pad is to provide a smooth flow of metal through the die, prevent chilling of the billet nose, and lubricate the die entrant area.

(5) There is no absolute billet temperature for the three alloys studied. There is a billet temperature range that will result in acceptable defect-free extrusions. The billet temperatures are also a function of alloy content. AISI 4340 is the least sensitive; it can be extruded successfully with temperatures as low as 1950F and as high as 2250F. PH 14-8 Mo is more sensitive to billet temperature than AISI 4340; it must be extruded at between 1975 and 2250F. 18% Ni maraging steel is the most temperature-sensitive of the three alloys studied. The billet temperature must be 2075F ±25F as measured by Ray-O-Tube type thermopiles.

(6) The die life of cobalt-base ALX-6 dies was excellent. Most dies were used at least twice and one die was used seven times before being scrapped. A zirconium oxide coating is necessary to prevent die wash. The coating process, however, is not critical. Conventional flame-sprayed dies performed as well as plasma-sprayed dies.

(7) The performance of repair-welded cobalt-base dies is equal to that of a new die for extruding AISI 4340 and PH 14-8 Mo. Repair-welded dies cannot, however, be used to extrude 18% Ni maraging steel.

(8) High container-liner temperatures are not required. Container-liner temperatures above 600F are not recommended because of upset and damage to the liner. The time the billet is in contact with the liner is about five seconds. The heat

lost from the billet to the liner is insignificant between liner temperatures of 600 and 1000F.

(9) Billet transfer time should be between 10 and 30 seconds for 3.25-inch-diameter billets. Full-length acceptable extrusions were produced using transfer times as long as 30 seconds. Transfer time, however, must not be less than 10 seconds or the billet surfaces will not be coated adequately with glass.

(10) Ram speed is a much better parameter to measure material "resistance to flow" than ram pressure. Consistently good 18% Ni maraging steel extrusions were produced at an average ram speed of 2.2 inches per second. The average ram speed for torn or defective extrusions was 4.1 inches per second. No correlation was found between extrusion quality and ram pressure.

(11) The ram speed during extrusion can accelerate from less than one inch per second to more than seven inches per second. This may be a peculiarity of the 1,200-ton Lowey extrusion press, as ram speeds for other extrusion presses are reported to be constant. The ram speed at upset must be at least one inch per second to prevent blocking the press.

(12) Post-extrusion thermal treatments are required for all three alloys to stretcher-straighten them to the target straightness requirements of this program. AISI 4340 extrusions were held at 1225F for two hours, furnace cooled to 900F, and finally air cooled to room temperature. PH 14-8 Mo extrusions were held at 1800F for five minutes and air cooled. 18% Ni maraging steel was overaged at 1150F for one hour and air cooled. These thermal treatments increased the ductility of the extrusions enough to allow stretcher straightening.

(13) The heat-treat response of AISI 4340 and PH 14-8 Mo extrusions is excellent. Target mechanical properties cited in the introduction were exceeded for these two alloys. The heat-treat response of 18% Ni maraging steel extrusions produced in this program is low. Both strength and ductility are below the target values.

b. Laboratory Testing

(1) A fast, inexpensive test method to select extrusion glass lubricants was developed. A visual comparison of the flow, wettability, and surface reactions with known glass lubricants provided a basis for comparison and selection of glass lubricants.

(2) The conclusions drawn from Gleeble testing are as follows:

(a) The flow stress of AISI 4340 is both temperature- and strain-rate-sensitive between 2100 and 2300F. The flow stress of AISI 4340 nearly doubles by increasing the strain rate from 1-sec^{-1} to 6-sec^{-1}. Increasing the test temperature from 1900 to 2300F reduces the flow stress 50 percent. The hot ductility of AISI 4340 is temperature- and strain-rate-sensitive between 1900 and 2300F. Elongation increases as a function of increasing temperature and strain rate.

(b) The flow stress of 18% Ni maraging steel is nearly double that of AISI 4340 at temperatures between 1900 and 2300F. The hot ductility of maraging steel increases with increasing temperature and strain rate.

(c) The hot ductility of PH 14-8 Mo data shows little difference between 1-sec^{-1} and 6-sec^{-1} strain rates for all three temperatures tested. The data, however, show a drastic reduction in ductility between 2100 and 2300F. Two mechanisms are proposed as possible explanations for the observed behavior: (1) grain boundary precipitation reaction, and (2) incipient melting.

(d) Gleeble testing is an excellent means of establishing the hot ductility and flow stress of steel alloys. The Gleeble data are most applicable to analytical deformation studies involving the elusive "resistance to flow" K factor.

2. PHASE II, DRAWING PROCESS

a. Drawing Operation

(1) The costly and time-consuming "pointing" operation has been completely eliminated by using an adjustable draw die arrangement invented during this program. Ninety-one extrusions were drawn using the adjustable draw die.

(2) A reproducible room temperature drawing process for 20-foot-long PH 14-8 Mo, AISI 4340, and 18% Ni maraging steel extrusions was developed to meet the target dimensions of 0.040-inch thickness for extruded tee shapes.

(3) One hundred fifteen extrusions were drawn in developing a practice for the three alloys. The total number of passes through the die was 302. The lubricant used for room temperature drawing 18% Ni maraging steel and AISI 4340 was a graphite-base paste (trade name "Fel-Pro C-300"). The lubricant did not have to be re-applied between passes through the die. A satisfactory lubricant for room temperature drawing PH 14-8 Mo extrusions was a conversion coating ("Bonderite 70"), plus "Teflon" or soap. The combination of a conversion coating and a surface lubricant effectively prevented any metal pickup on the die and eliminated die chattering (stick-slip).

(4) The average percent reduction per pass for the three alloys under development was:

AISI 4340	PH 14-8 Mo	18% Ni Maraging Steel
11.4%	12.9%	8.7%

The total reduction in thickness from the as-extruded dimensions average was:

32.5%	33.0%	34.6%

(5) The drawing process improved the surface finish of PH 14-8 Mo, AISI 4340, and 18% Ni maraging steel. The average as-extruded surface roughness was RMS 84. After drawing, the surface roughness was RMS 20-30.

(6) The procedure developed for drawing PH 14-8 Mo extrusions down to the target thickness of 0.040 inch required in-process anneals if the hardness exceeded R_c 30. The in-process anneals, however, did not lower the heat treat response of the alloy. The mechanical properties of 0.040-inch-thick drawn extrusions, heat treated to the SRH 950 condition, averaged 200-ksi yield, 226-ksi ultimate, and 11-percent elongation. The delta ferrite content of PH 14-8 Mo was estimated at 10 percent.

(7) The drawing procedure developed for both AISI 4340 and 18% Ni maraging steel did not require any thermal treatments between passes through the die. Both alloys were drawn readily at room temperature.

(8) The drawing process reduced the thickness deviations between the base and stem of the tee. The average thickness deviation of extruded PH 14-8 Mo was 0.0074 inch. The average thickness deviation after drawing down to a nominal 0.040 inch was 0.0039 inch.

All

b. Stretcher-Straightening

(1) Stretcher-straightening of AISI 4340 and PH 14-8 Mo was accomplished after annealing. AISI 4340 drawn tee shapes were annealed at 1225F for two hours, furnace-cooled to 900F, and air-cooled to room temperature. PH 14-8 Mo drawn shapes were annealed for five minutes at 1800F and cooled to room temperature. The stretcher-straightening of both alloys was accomplished at room temperature.

(2) Stretcher-straightening of 18% Ni maraging steel 0.040-inch thin-drawn tee shapes was possible at 1100F. The low strain-hardening coefficient and small cross section of the drawn shapes limited room temperature straightening. Localized yielding during stretching of the 20-foot-long shapes without any cold-work strengthening made it impossible to stretch-straighten the 0.040-inch drawn shapes at room temperature.

c. Laboratory Testing

(1) The Rockwell hardness of as-extruded PH 14-8 Mo material was R_c 25 compared to R_b 75 for annealed material. The hardness of annealed material increased to R_c 20 after six percent total stretch. The hardness of material in the as-extruded condition, however, increased to R_c 36 after the same amount of stretch. The hardness in both conditions increased very little after nine percent total stretch. The maximum hardness observed before failure was R_c 38.

(2) The yield strength at 0.2 percent offset of as-extruded PH 14-8 Mo was significantly higher (~80 ksi) than annealed material after a six-percent stretch.

(3) Rockwell hardness was a good measure for change in strength of PH 14-8 Mo as a result of drawing but was not for 18% Ni maraging steel.

All

3. PHASE III, HEAT TREAT PROCESS

a. Production Operations

(1) A production process to heat treat 20-foot-long by 0.040-inch-thick extruded and drawn tee shapes was demonstrated. The schedule for heat treating AISI 4340 was as follows: (1) Austenitize at 1550F for 15 minutes and quench in a 400F neutral salt, hold for five minutes, and cool to room temperature. (2) "Snap" temper at 325F for 30 minutes and cool to room temperature. (3) Temper in the fixture developed for this program at 400F for two hours.

(2) The heat treat-response of AISI 4340 extruded and drawn material was excellent. Mechanical properties of specimens machined from drawn tee shapes were higher than the target values of this program. The average mechanical properties of heat treated AISI 4340 were: 278.5-ksi ultimate, 219.5-ksi yield, and 6.2-percent elongation.

(3) A production process also was developed for heat treating PH 14-8 Mo extruded and drawn shapes. The heat-treat schedule was as follows: (1) Solution anneal at 1825F for seven minutes and air cool. (2) Austenitize at 1700F for 15 minutes and air cool. (3) Cool within one hour after removal from the austenitizing treatment to -100F and hold for eight hours. (4) Precipitation harden at 950F for one hour.

(4) The heat-treat response of PH 14-7 Mo extruded and drawn tee shapes was excellent. The mechanical properties of drawn PH 14-8 Mo tee shapes in the SRH 950 condition averaged 200-ksi yield, 226-ksi ultimate, and 11-percent elongation. The delta ferrite content of PH 14-8 Mo was estimated to be 10 to 11 percent.

(5) The production process for heat treating 18% Ni maraging steel tee shapes was as follows: (1) Solution anneal at 1500F for 30 minutes and air cool. (2) Age harden at 900F for three hours.

(6) The strength and ductility level of heat treated 18% Ni maraging steel was comparable to that of sheet and strip. The averate mechanical properties of extruded, drawn, and heat treated 18% Ni maraging steel are 248.9 ksi, 252.2 ksi, and 2.5% for yield, ultimate, and elongation, respectively. Both stretch and ductility were, however, lower than the target mechanical properties set for the program.

APPENDIX I

EXTRUSION OPERATIONS RECORD

1. CONSTANT CONDITIONS:

Accumulator Pressure:	2,650 psi*	Die Material:	Cobalt Base A1X-6	Material Identity:	
Liner Diameter:	3.44 inches	Die Coating:	Zirconium Oxide	L =	AISI 4340
Billet Configuration:	(See Text)	Extrusion Ratio:	45:1	M =	18% N: Maraging Steel
Die Configuration:	Tee (See Text)	Die Temperature:	R.T.	K =	PH 14-8 Mo
Die Glass Configuration:	Pad (See Text)				

2. VARIABLE CONDITIONS:

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Ram Speed (in/sec) Max	Pressure (psi) Break Thru	Pressure (psi) Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
1	Air Melt 4340	2100	900	N-12	N-16	10	---		---		---	11.0	Glass plugged die.
2	Air Melt 4340	2100	900	N-12	N-16	10	---		---		---	13.0	Glass plugged die.
3	Air Melt 4340	2050	1000	N-5	N-17	10	2.75**		2,000**		---	9.0	13.8-ft. extrusion.
4	L-24	2050	1000	N-5	N-17	9	2.75**		2,000**		---	9.0	12.1-ft. extrusion.
5	L-19	2060	900	N-5	N-17	1	2.75**		2,000**		---	15.0	21.3-ft. extrusion.
6	L-18	2050	800	N-5	N-19	6	2.75**		2,000**		---	9.0	20.7-ft. extrusion.
7	L-25	2050	800	N-5	N-21	5	2.75**		2,000**		---	11.0	21.5-ft. extrusion.
8	L-23	2050	800	N-5	N-16	3	2.75**		2,010**		---	8.0	19.8-ft. extrusion.
9	L-23	2050	800	N-5	N-16	7	2.75**		2,100**		---	6.0	18.3-ft. extrusion.
10	L-15	2050	800	N-5	N-16	2	2.75**		2,000**		---	9.0	18.9-ft. extrusion.
11	L-6	2050	800	N-5	N-16	8	2.75**		2,000**		---	9.0	19.2-ft. extrusion.
12	L-10	2050	800	N-5	N-16	4	2.75**		2,000**		---	12.0	19.9-ft. extrusion.
13	L-39	2100	675	N-5	1 oz N-17 +G. W.	35	0.6	5.8	2220	1770	---	15.0	Extrusion base undersize caused by glass filling die corners.
14	L-52	2100	700	N-5	2 oz N-17 +G. W.	28	0.3	---	---	---	---	18.0	Glass plugged die; 2-oz. pad too large.
15	L-49	2200	725	N-5	1 oz N-21	27	0.5	3.1	2510	2320	2300+	12.0	Extrusion badly rippled for entire length; billet temperature too high.

* Except for Ext. Nos. 33 and 34, which was 2950

** Average values

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Max	Pressure (psi) Break Thru	Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
16	L-48	2100	700	N-5	1 oz N-21	32	0.8 (Includes upset)	6.5	2500	2010	2285	12.0	24-ft. extrusion; first 3 ft. undersize.
17	L-50	2100	700	N-5	1 oz N-22	22	0.2	---	---	---	---	13.0	Glass partially extruded and then plugged die.
18	L-53	2200	700	N-5	None	24	0.6	---	---	---	---	14.0	Stall
19	L-54	2100	750	N-5	1 oz N-11	33	1.6	---	---	---	---	14.0	Stall
20	L-37	2200	740	N-5	G. W.	41	1.3	5.1	2540	2190	2265	10.8	27-ft. extrusion; good surface finish. Last 6 ft. has slight ripple.
21	L-55	2150	660	N-5	1 oz N-21 +G. W.	26	1.4	7.7	1840 (1/2 sec) ---	1560 1870 (1 sec)	2300+	16.8	About 7 ft. of good extrusion on front: badly rippled in center to last 6 ft.
22	L-27	2150	660	N-5	1 oz N-16 +G. W.	40	1.2	5.2	2500	2100	---	18.0	27-ft. extrusion with left base slightly rippled for 18 ft. Remainder looks very good.
23	L-34	2120	675	N-5	1 oz N-16 +G. W.	31	1.4	6.3	2460	2060	2300+	18.0	29 1/2-ft. extrusion, first 18 in. did not completely fill. Remainder looks excellent.
24	L-36	2100	675	N-5	1 oz N-16 +G. W.	37	1.6	5.3	2600	2250	---	15.6	26-ft. extrusion. First 3 ft. did not completely fill; remainder 23 ft., excellent.
25	L-31	2100	675	N-5	1 oz N-16 +G. W.	20	1.2	5.1	2530	2070	2300+	16.2	24-ft. extrusion. Surface finish looks good and appears within tolerance.
26	L-35	2050	680	N-5	1 oz N-16 +G. W.	46	1.6	5.8	2490	2160	---	18.0	21-ft. extrusion. Looks very good.
27	L-32	2030	700	N-5	1 oz N-17 +G. W.	18	1.4	3.7	2780	2360	---	16.8	36-ft. extrusion: 19 ft. look very good: remainder was rippled on left leg of tee.
28	L-42	2050	700	N-5	G. W.	17	1.7	2.3	2790	2450	---	15.0	13-ft. of good extrusion. The surface looks very good.
29	L-29	2100	750	N-5	1 oz N-16 +G. W.	Recoated #8	1.3	6.7	2700	2240	2292	13.2	27-ft. extrusion with slight ripple on left leg in center of extrusion.
30	L-45	2100	760	N-5	1 oz N-16 +G. W.	Plasma Sprayed Recoat #5	1.6	6.8	2800	2470	2300+	9.6	22-ft. long extrusion; looks very good.
31	L-41	2100	760	N-5	1 oz N-22 +G. W.	Recoated #4	1.4	7.2	2740	2140	2278	15.0	27-ft. extrusion with last 3 ft. slightly rippled.
32	L-9	2100	675	N-5	1 oz N-22 +G. W.	Coated in one finish #48	1.5	6.3	2760	2350	2215	16.0	19-ft. extrusion; looks very good.
33	M-85	2250	650	N-5	1 oz N-16 +G. W.	13	1.4	6.2	3370	2510	2300+	17.4	First 6 ft. good extrusion; the remainder badly rippled and torn.

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec)		Pressure (psi)		Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
							Min.	Max	Break Thru	Run			
34	M-124	2150	630	N-5	1 oz N-16 +G. W.	11	1.5	6.2	3240	2550	2300+	14.4	21-ft. extrusion that looks very good.
35	L-38	2000	590	N-5	1 oz N-16 +G. W.	38	0.1	3.6	3300	2650	2035	14.0	27-ft. extrusion. First 3 ft. of base were undersize. Surface finish looks excellent.
36	L-57	2000	600	N-5	1 oz N-16 +G. W.	42	2.95	3.75	3250	2530	2071	12.0	28-ft. extrusion with excellent surface finish and dimensions.
37	L-28	1950	600	N-5	1 oz N-16 +G. W.	36	***	---	3400	---	---	12.0	About 3-ft. extrusion and stall. 1950F is below minimum billet temperature.
38	L-30	1950	650	N-5	1 oz N-16 +G. W.	22	***	---	3450	---	2000	11.0	About 4-ft. extrusion and stall. 1950 is below minimum billet temperature.
39	L-3	2100	650	N-5	1 oz N-11 +G. W.	11	***	---	3550	---	---	16.0	Stall
40	L-60	2100	650	CSF	1 oz N-16 +G. W.	35	1.5	7.4	3000	1750	2148	12.0	24-ft. extrusion with slight glassing after 4-ft., and continues for about 8 ft. Surface finish is very good.
41	L-66	2100	675	CSF	1 oz N-16 +G. W.	4	2.1	8.6	2400	1650	1630	18.0	25 1/2-ft. extrusion with very good surface finish.
42	L-61	2100	675	N-5	1 oz N-16 +G. W.	44	1.85	6.7	2800	2220	---	13.0	23-ft. extrusion that looks very good.
43	L-51	2100	700	N-5	1 oz N-16 +G. W.	51	2.1	7.1	2800	1790	2300+	13.0	22-ft. extrusion that looks very good.
44	M-118	2125	700	N-5	1 oz N-16 +G. W.	48	1.4	4.2	3900	2950	2300+	11.0	11-ft. extrusion with about 6 ft. of good shape. Left leg of last 4 ft. was badly rippled.
45	M-105	2150	700	N-5	1 oz N-16 +G. W.	37	3.1	5.05	4200	2990	2115	14.0	12-ft. extrusion with some tearing at back.
46	M-75	2150	700	N-5	1 oz N-16 +G. W.	40	0.7	4.4	3900	2860	2300+	13.0	23 1/5-ft. extrusion with some ripples along last 7 ft. Appears that ripples can be removed.
47	M-76	2150	700	N-5	1 oz N-16 +G. W.	18	1.3	4.5	3950	3000	2300+	12.0	24 1/2-ft. extrusion that did not fill on left leg for first 10 ft. Remainder looks good.
48	L-64	2100	700	N-5	1 oz N-2 +G. W.	14	1.6	3.7	3100	2210	2300	13.0	20-ft. extrusion that looks very good.
49	M-77	2150	750	N-5	1 oz N-16 +G. W.	12	1.3	4.1	3820	3000	2300+	13.0	18-ft. extrusion torn on right leg after first 8 ft. Surface finish looks good. Some ripples on left leg.
50	M-104	2150	750	CSF	1 oz N-16 +G. W.	5	1.25	4.1	3850	2820	2300+	16.0	26-ft. extrusion that looks good. Some die marks on bottom of tee.
51	M-73	2150	750	N-5	1 oz N-16 +G. W.	16	1.6	4.2	---	---	---	17.0	Stall
52	K-301	2100	750	N-5	1 oz N-16 +G. W.	47	0.5	4.0	3250	2690	2015	14.0	22 1/2-ft. extrusion that looks very good. Surface finish is excellent.

*** Equipment Malfunction

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Ram Speed (in/sec) Max	Pressure (psi) Break Thru	Pressure (psi) Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
53	K-302	2100	750	N-5	1 oz N-16 +G. W.	---	3.55	4.6	3250	2710	2300+	13.0	24 1/2-ft. extrusion that looks very good. Excellent surface finish.
54	M-83	2150	650	CSF	1 oz N-16 +G. W.	99	2.5	4.85	3040	2860	1150	18.0	Extruded about 2 ft. and then stall.
55	M-112	2150	650	CSF	1 oz N-16 +G. W.	80	2.95	4.35	2650	2360	2072	16.8	18-ft. extrusion with very good surface finish. Slight die wash in fillet.
56	M-114	2150	650	CSF	1 oz N-16 +G. W.	95	5.2	5.45	---	---	---	13.8	Stall
57	M-103	2150	670	CSF	1 oz N-16 +G. W.	68	2.45	4.7	---	---	---	15.6	Die backer put on incorrectly, causing stall; 1/2 glass matt thickness, 0.08 inch thick.
58	M-100	2150	670	CSF	1 oz N-16 +G. W.	93	2.5	4.55	2840	2790	2300+	15.6	21 1/2-ft. extrusion with about 6 ft. of good extrusion. The remainder is badly torn.
59	M-123	2150	670	CSF	Graphite Ring Design #3	83	4.8	5.45	---	---	---	15.0	Stall
60	M-109	2200	680	CSF	1 oz N-16 +G. W.	79	5.6	6.4	2860	---	---	17.4	2-ft. extrusion and then stall.
61	K-321	2100	680	CSF	1 oz N-16 +G. W.	76	0.8	1.05	2940	2910	---	15.6	2-ft. extrusion and then stall.
62	K-327	2100	680	CSF	1 oz N-16 +G. W.	98	0.8	1.1	3050	2600	2228	20.4	21 1/2-ft. extrusion with slight ripples on left leg.
63	K-312	2100	680	CSF	1 oz N-16 +G. W.	100	0.6	1.0	3050	2550	2300+	19.2	22-ft. extrusion with slight ripple on left leg.
64	K-334	2075	690	CSF	1 oz N-16 +G. W.	92	---	---	3000	2550	2300+	15.0	19-ft. extrusion that looks very good.
65	K-320	2075	660	CSF	1 oz N-16 +G. W.	81	1.75	4.0	3150	2650	1922	15.0	20 1/2-ft. extrusion that looks very good; no defects and appears to be dimensionally correct.
66	K-329	2050	680	CSF	1 oz N-16 +G. W.	70	5.2	5.65	3400	2620	2179	15.0	19-ft. extrusion with poor surface finish on right leg.
67	K-306	2025	700	CSF + N-5	1 oz N-16 +G. W.	89	3.1	5.0	3550	2600	2300+	14.4	18-ft. extrusion with a few very small tears along the left leg of last 6 ft.
68	K-308	2000	700	CSF + N-5	1 oz N-16 +G. W.	74	2.85	4.15	3300	2650	2300+	30.6	18-ft. extrusion with slight tears along left leg of last 10 ft. Fair surface finish.
69	K-303	1975	700	CSF + N-5	N-22 +G. W.	85	3.1	5.2	3550	3000	1170	14.4	2-ft. extrusion and then stall.
70	K-322	2100	700	CSF + N-3	1 oz N-16 +G. W.	88	3.25	4.5	3450	3000		15.0	2-ft. extrusion and then stall.
71	K-325	2100	700	CSF + N-5	1 oz N-16 +G. W.	84	3.2	4.1	3550	2850	1720	13.2	21-ft. extrusion with small tears along right leg for entire length. Poor surface finish.
72	K-307	2100	675	CSF + N-5	1 oz N-16 +G. W.	25	2.6	4.6	3700	2900	2300+	14.4	26-ft. extrusion with waves along entire length.

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Max	Pressure (psi) Break Thru	Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
73	K-332	2050	675	CSF + N-5	1 oz N-16 +G. W.	23	3.7	4.45	3300	2650	2195	12.0	24-ft. extrusion with waves along the left leg for entire length.
74	M-97	2200	675	CSF + N-5	1 oz N-16 +G. W.	29	4.1	5.25	3650	---	---	13.2	6-in. extrusion and then stall.
75	K-324	2050	675	CSF + N-5	1 oz N-16 +G. W.	31	2.5	4.05	3560	2510	2020	15.6	22-ft. extrusion with very good surface finish and dimensions. No defects.
76	K-331	2050		CSF + N-5	1 oz N-16 +G. W.	39	3.3	4.55	3680	---	---	13.2	1-ft. extrusion and then stall.
77	K-304	2050	675	N-5	1 oz N-16 +G. W.	32	1.45	4.0	3750	2900	2300+	12.6	Excellent 21-ft. extrusion.
78	K-326	2050	675	N-5	1 oz N-16	13	3.9	4.95	3800	---	---	10.2	2-ft. extrusion and then stall.
79	K-310	2150	700	N-24	1 oz N-16 +G. W.	68	---	---	3220	3000	---	17.2	20 1/2-ft. extrusion with small tears on left leg after first 6 ft. Excellent surface finish
80	K-316	2150	700	N-24+ Matt	1 oz N-16 +G. W.	14	1.3	3.1	3100	3000	2310	29.0	22-ft. extrusion with small tears on left leg for back 3 ft. The right leg rippled on back 7 ft.
81	K-311	2100	700	N-24	1 oz N-16 +G. W.	47	---	---	3400	3225	No Exit	19.0	
82	K-315	2100	700	N-24	N-16	83	0.6	4.4	3400	3100	No Exit	16.0	
83	K-330	2175	700	N-24	N-16	23	1.2	5.2	3175	2925	2300	14.2	28-ft. extrusion with ripple on left leg for whole length.
84	K-333	2175	700	N-5	1 oz N-16 +G. W.	31	2.4	5.3	3025	2925	No Exit	14.0	27-ft. extrusion with no defects and very good surface finish.
85	K-319	2175	700	N-5	1 oz N-16 +G. W.	33	2.35	4.25	3175	3050	2250	16.5	25-ft. extrusion with small tears starting after 14 ft. Excellent surface finish.
86	K-335	2200	700	N-5	1 oz N-16 +G. W.	98	3.7	6.5	2750	2725	2300	17.0	22-ft. extrusion with no defects and good surface finish.
87	K-338	2200	725	N-5	1 oz N-16 +G. W.	29	3.4	6.8	2750	2725	2275	15.0	26-ft. extrusion with very slight ripple on right leg for first 9 ft.
88	K-313	2200	725	N-5	1 oz N-16 +G. W.	90	3.8	6.9	2725	2700	2310	13.5	21-ft. extrusion with right leg rippled for 18 ft. Poor surface finish on bottom, but excellent on top.
89	K-339	2250	725	N-5	1 oz N-16 +G. W.	16	3.1	7.1	2725	2700	2310	19.2	27-ft. extrusion with small tears on left leg starting at 14 ft.
90	K-341	2250	725	N-5	1 oz N-16 +G. W.	12	2.7	8.1	2625	2525	2240	16.2	25-ft. extrusion with right leg rippled and left leg tears. Good surface finish.
91	K-356	2250	725	N-5	1 oz N-16 +G. W.	35	3.0	6.0	2900	2850	2165	16.0	22 1/2-ft. extrusion with no defects and excellent surface finish.
92	K-347	2250	725	N-5	1 oz N-16 +G. W.	36	0.9	8.6	2400	2425	2090	15.0	23 1/2-ft. extrusion with left leg rippled for 10 ft. The stem has slight irregular ripples.
93	K-337	2250	725	N-5	1 oz N-16 +G. W.	11	2.5	7.2	2525	2500	2300	14.8	23-ft. extrusion with right leg rippled for entire length.

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Max	Pressure (psi) Break Thru	Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
94	K-346	2200	725	N-5	1 oz N-16 +G. W.	32	2.4	5.9	2875	2725	No Exit	15.0	24-ft. extrusion that is badly twisted as a result of jumping run-out trough. Can be straightened.
95	K-354	2200	725	N-5	1 oz N-16 +G. W.	30	2.4	6.0	2925	2775	2310	13.8	25-ft. extrusion with very slight ripple on stem. Surface finish looks very good.
96	K-350	2200	725	N-5	1 oz N-16 +G. W.	81	2.7	6.6	2675	2600	2255	---	27-ft. extrusion with irregular ripples on tee. Right leg badly rippled.
97	L-33	2050	675	N-5	1 oz N-16 +G. W.	N-4	3.0	9.0	2250	2200	1920	15.0	21-ft. defect-free extrusion. Excellent surface finish.
98	L-14	2050	675	N-5	1 oz N-16 +G. W.	N-33	---	---	---	---	1890	14.4	25-ft. extrusion. Excellent surface finish. No defects.
99	L-8	2050	675	N-5	1 oz N-16 +G. W.	N-14	3.0	9.5	2150	2100	1820	15.0	23-ft. extrusion. No defects. Excellent surface finish.
100	L-4	2050	675	N-5	1 oz N-16 +G. W.	N-83	3.0	8.0	2550	2500	1805	13.8	26-ft. extrusion. No defects. Excellent surface finish.
101	L-5	2050	675	N-5	1 oz N-16 +G. W.	N-41	2.5	8.5	2750	2700	2010	14.4	24-ft. extrusion. No defects. Excellent surface finish.
102	K-352	2100	750	N-5	1 oz N-16 +G. W.	N-32	3.5	6.8	2750	2675	2080	22.2	21-ft. extrusion. No defects.
103	K-357	2100	750	N-5	1 oz N-16 +G. W.	N-12	3.2	7.0	2700	2575	1970	21.6	23-ft. extrusion. No defects.
104	K-355	2100	750	N-5	1 oz N-16 +G. W.	N-15	3.2	7.7	2525	2450	2020	15.6	22-ft. extrusion with very good surface finish except for small area in fillet.
105	M-87	2150	750	N-5	1 oz N-16 +G. W.	N-35	0.7	3.5	3200	3020	2070	14.4	23-ft. extrusion; very small tears on left leg. Good surface finish.
106	M-110	2200	750	N-5	1 oz N-16 +G. W.	N-31	---	3.8	3250	3100	2150	15.0	Stall after 6 in. of product.
107	M-92	2200	750	N-5	1 oz N-16 +G. W.	N-23	---	4.0	3300	3120	2075	16.2	Stall
108	M-107	2250	750	N-5	1 oz N-16 +G. W.	N-90	3.0	6.2	2840	2650	2150	16.2	22-ft. extrusion with small tear in center. Very good surface and dimensions.
109	M-89	2250	750	N-5	1 oz N-16 +G. W.	N-81	3.0	7.0	2700	2570	2155	15.0	25-ft. extrusion with torn stem after first 7 ft. Fair surface.
110	M-117	2250	750	N-5	1 oz N-16 +G. W.	N-30	---	---	3250	---	2155	16.0	Stall
111	M-93	2250	700	N-5	1 oz N-16 +G. W.	N-2	0.6	7.0	2600	2250	---	12.6	Front and back of extrusion O.K. Middle badly torn up. Hot center in billet.
112	M-81	2200	700	N-5	1 oz N-16 +G. W.	N-37	0.5	4.9	2800	2500	2175	15.0	6 ft. on each end of extrusion O.K. The stem separated from base in center.
113	M-94	2175	700	N-5	1 oz N-16 +G. W.	N-68	---	---	2725	2450	1820	15.0	Very good 21-ft. extrusion with very fine scratches in fillet of stem.
114	M-151	2175	700	N-5	1 oz N-16 +G. W.	N-12	3.0	6.5	2450	2420	1800	13.8	O.K. on each end of extrusion. Stem sheared off in center.
115	M-166	2150	700	N-5	1 oz N-16 +G. W.	N-20	2.5	5.3	2730	2680	2120	12.6	25-ft. extrusion. First and last 10 ft. very good. Stem separated in center.

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec)		Pressure (psi)		Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
							Min.	Max	Break Thru	Run			
116	M-160	2125	700	N-5	1 oz N-16 +G. W.	N-26	2.5	6.5	2420	2420	1890	12.6	First and last 6 ft. of extrusion O.K. Middle badly torn.
117	M-72	2075	700	N-5	1 oz N-16 +G. W.	N-15	3.3	5.0	2700	2700	1990	13.2	Full length extrusion with good dimensions and fair surface finish.
118	M-86	2075	700	N-5	1 oz N-16 +G. W.	N-24	3.0	3.8	2870	2870	2040	22.8	Full length extrusion with some ripples on right leg of last 6 ft.
119	M-98	2095	700	N-5	1 oz N-16 +G. W.	N-90	2.0	6.0	2600	2600	2200	18.0	Extrusion badly torn.
120	M-119	2075	700	N-5	1 oz N-16 +G. W.	N-17	1.0	3.6	3050	3050	1985	16.0	14-ft. extrusion with very good surface and dimensions.
121	M-73	2075	700	N-5	1 oz N-16 +G. W.	N-5	1.5	3.0	2980	2950	2040	19.2	Very good full length extrusion with a few very small tears on back edges.
122	M-121	2075	700	N-5	1 oz N-16 +G. W.	N-22	2.9	4.5	2800	2800	2080	16.8	Full length extrusion with excellent dimensions. Poor surface in fillet area.
123	M-95	2090	700	N-5	1 oz N-16 +G. W.	N-46	2.5	5.0	2700	2750	2090	18.6	Full length extrusion with good surface finish except in fillet area.
124	M-153	2090	700	N-5	1 oz N-16 +G. W.	N-39	3.1	5.1	2770	2770	2070	17.4	Full length extrusion with fair surface finish in fillet and very good elsewhere.
125	M-150	2090	700	N-5	1 oz N-16 +G. W.	N-36	2.6	5.0	2850	2850	2110	15.0	
126	M-154	2090	700	N-5	1 oz N-16 +G. W.	N-91	2.2	4.1	2900	2880	2020	12.0	Bad die. The extrusion is outside target dimensions.
127	M-158	2100	625	N-5	1 oz N-16 +G. W.	N-40	2.7	5.0	2725	2725	2090	19.8	Full length extrusion with some die marks in fillet area. Surface finish very good.
128	M-155	2100	625	N-5	1 oz N-16 +G. W.	N-31	2.5	4.2	2850	2850	2090	14.4	25-ft. extrusion with very good surface finish and dimensions.
129	M-106	2100	650	N-5	1 oz N-16 +G. W.	N-33	3.0	5.6	2650	2650	2100	21.6	Excellent full length extrusion.
130	M-156	2100	700	N-5	1 oz N-16 +G. W.	N-28	2.5	4.8	2825	2800	2040	22.2	Full length extrusion with very good surface finish and excellent dimensions.
131	M-167	2050	700	N-5	1 oz N-16 +G. W.	N-35	2.8	5.0	2950	2900	2070	19.8	Excellent full length extrusion.
132	M-159	2000	700	N-5	1 oz N-16 +G. W.	N-98	---	---	3320	---	1990	16.8	Stall
133	M-96	2025	550	N-5	1 oz N-16 +G. W.	N-11	2.1	5.2	3125	3050	2040	16.2	Full length extrusion with improved surface finish in fillet area.
134	M-164	2025	550	N-5	1 oz N-16 +G. W.	N-41	4.3	5.7	2800	2780	2080	19.2	Very good extrusion with excellent surface finish except for fillet area.
135	M-163	2025	550	N-5	1 oz N-16 +G. W.	N-77	2.5	5.7	3000	2950	1975	17.4	19-ft. extrusion with fillet area corroded away. Die failure.
136	M-161	2025	525	N-5	1 oz N-16 +G. W.	N-81	1.5	3.9	3270	3170	1990	18.0	Excellent extrusion.
137	M-152	2025	500	N-5	1 oz N-16 +G. W.	N-83	1.4	3.5	3360	3300	2015	15.0	Stall

2. VARIABLE CONDITIONS (Continued):

Ext. No.	Billet Material Identification	Billet Temp. (F)	Liner Temp. (F)	R. D. Glass Code No.	Die Glass Code No.	Die No.	Ram Speed (in/sec) Min.	Ram Speed (in/sec) Max	Pressure (psi) Break Thru	Pressure (psi) Run	Exit Temp. (F)	Billet Trans. Time (Sec.)	Remarks
138	---	2050	500	N-5	1 oz N-16 +G. W.	N-7	3.0	6.7	2800	2800	1950	17.4	Weld-repaired die failed. Fillet area washed out.
139	M-165	2050	500	N-5	1 oz N-16 +G. W.	N-38	2.9	5.0	3100	3100	2090	16.2	Excellent full-length extrusion.
140	M-157	2050	500	N-5	Graphite	N-88	---	---	3400	Max.	2000	16.8	Stall
141	M-115	2050	500	N-5	1 oz N-16 +G. W.	N-18	2.1	4.1	3200	3150	2030	15.6	25-ft. excellent extrusion.
142	M-71	2050	530	N-5	1 oz N-16 +G. W.	N-32	1.2	3.8	3300	3230	2000	17.4	23-ft. excellent extrusion.
143	M-101	2050	550	N-5	1 oz N-16 +G. W.	N-51	---	---	3430	Max.	1860	18.0	Stall

APPENDIX II

SPECIFICATION FOR AISI 4340, STEEL CHROME-NICKEL-MOLYBDENUM EXTRUDED TEE SHAPES

1. SCOPE

1.1 Scope. This specification covers 4340 alloy steel extrusions for aircraft quality parts.

1.2 Classification.

1.2.1 Physical Condition. 4340 extrusions shall be furnished in one of the following product forms:

a. Extruded and straightened
b. Extruded, drawn, and straightened
c. Extruded, drawn, straightened, and heat treated

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of the invitation for bids form a part of the specification to the extent specified herein:

a. Specifications

Military

MIL-S-5000B	Steel, Chrome-Nickel-Molybdenum (4340 or E4340) Bars and Reforging Stock
MIL-I-6866B	Inspection, Dye Penetrant

b. Standards

Federal

Federal Standard No. 48	Tolerances for Steel and Iron Wrought Products
Federal Test Method Standard No. 151	Metals, Test Methods for

c. Other Publications

MIL-STD-163	Steel Mill Products, Preparation for Storage and Shipment

MIL-STD-183	Continuous Identification Marking of Iron
MIL-STD-430	Macrograph Standards for Steel Bars, Billets, and Blooms
Norair Process Specification IT-32.5	Ultrasonic Inspection
MIL-I-6868C	Magnetic Particle Method

3. REQUIREMENTS

3.1 Material

3.1.1 Chemical Composition. The chemical composition for AISI 4340 shall be as specified in Table I.

TABLE I. CHEMICAL COMPOSITION

Element	Analysis (Weight - Percent)	Check Analysis Tolerance (percent)(1)
Carbon	0.03 - 0.043	± 0.02
Manganese	0.65 - 0.85	± 0.03
Phosphorus	0.025 (max)	± 0.005
Sulfur	0.025 (max)	± 0.005
Silicon	0.20 - 0.35	± 0.02
Nickel	1.65 - 2.00	± 0.05
Chromium	0.70 - 0.90	± 0.03
Molybdenum	0.20 - 0.30	± 0.02

(1) Individual determinations may vary from the specified range to the extent shown in the Check Analysis column.

3.2 Grain Size. The austentic grain size of the AISI 4340 extrusion billets shall be predominantly Number 5 or finer.

3.3 The AISI 4340 extruded, drawn, and straightened material shall meet the following mechanical properties shown in Table II after heat treatment, as specified in Section 3.4.

TABLE II. MECHANICAL PROPERTIES OF 4340 STEEL EXTRUSIONS

Property (1)	Condition A	Condition C
Ultimate Tensile Strength, ksi	150	260
Yield Strength, ksi	135	217
Elongation, % in 1-inch (min)	10.0	6.0

(1) The mechanical properties shown are to be measured in the longitudinal direction.

3.4 Heat Treatment. The extruded, drawn, and straightened parts shall be solution annealed at 1550 F for one hour, oil quenched, and/or neutral salt quenched. Temper material in the range of 400 to 500 F for two hours and air-cool to room temperature. (Solution annealing to be performed under controlled atmosphere conditions.)

3.5 Dimensional Properties

3.5.1 Straightness. The extruded and drawn 4340 material shall be straight to 0.010 inch per linear foot.

3.5.2 Twist. The extruded and drawn material shall not exceed one degree per foot of length, with a ten-degree maximum twist.

3.5.3 Flatness. The extruded and drawn part shall not exceed a flatness of 0.010 inch per inch.

3.5.4 Surface Roughness. The surface roughness shall be 100 microinch (RMS) or better.

3.5.5 Extrusion Length. The length of an extruded and drawn part shall be as specified on an applicable extrusion drawing.

3.6 Extrusion

3.6.1 Extrusion Billet Temperature. The maximum extrusion temperature shall be 2100 F.

3.6.2 Extrusion Ratio. The extrusion ratio shall be approximately 45 to 1, based on the container size of the extrusion press.

3.6.3 Structure. The extruded and drawn material shall be hot-cold worked sufficiently to produce a worked fibrous wrought product.

3.7 Workmanship. The material shall be uniform in quality and condition; free from foreign material, internal and external imperfections which are detrimental to the fabrication of parts or performance of the part in service. Spot grinding to remove minor defects from extruded parts is permissible provided specified minimum thickness tolerances are not exceeded.

3.8 Identification

3.8.1 Each extruded, drawn, and straightened part, unless otherwise specified, shall be identified in accordance with MIL-STD-183. The identification shall consist of the following:

a. Alloy Designation
b. Heat Number
c. Die Serial Number
d. Die Sequence Number
e. Extrusion Sequence Number
f. Name of Manufacturer

3.8.2 Extrusions or extrusion lots shall be marked or tagged with the following identification:

a. Specification Number
b. Heat Number
c. Quantity
d. Part Number
e. Extrusion Shape Number
f. Purchase Order Number

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection. Unless otherwise specified in the contract or applicable purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein.

4.2 Sampling Method. The product shall be selected randomly to represent each lot of material from one heat, offered for acceptance at one time.

4.2.1 Method. Samples shall be visually examined for conformance to the requirements of this specification.

4.3 Chemical Analysis. The chemical analysis of AISI 4340 as stated in Section 3.1.1 shall be determined in accordance with Federal Test Method Standard No. 151. Chemical elements shall be determined by wet chemical, spectrographic, conductimetric, or other acceptable analytical methods. In the event of dispute, analyses shall be by wet chemical techniques.

4.4 Tensile Tests. Two test samples shall be selected from a representative extruded and drawn part selected at random from one lot of material. The test specimens shall be made in accordance with Method 211, Federal Test Method No. 151, Type F-2.

4.5 Heat Treatment. The heat treatment of AISI 4340 steel shall be in accordance with Section 3.4 of this specification.

4.6 Grain Size. Specimens for grain size determination of the extrusion billets shall be determined in accordance with Procedure B, C, or D, Method 311, Federal Test Method No. 151, and MIL-STD-430. Specimens for grain structure of wrought extruded products shall be determined by metallographic examination in accordance with Federal Test Method No. 151.

4.7 Surface Defects. Inspection for material flaws and surface defects shall be done in accordance with MIL-I-6868A and MIL-I-6866B specifications.

4.8 Dimensional Inspection. Dimensional inspection shall be done in accordance with Federal Test Standard No. 48 and shall satisfy the requirements of Section 3.5 of this specification.

4.9 Rejection. Extruded parts not conforming to the specification or authorized modifications shall be subject to rejection. Requalification of any rejected lot of material shall be at the discretion of the procuring activity. All requests for retesting of any material lot shall be in writing to the procuring activity.

4.10 Reports. The product supplier shall furnish three copies of a test report with each shipment. The report shall include name of manufacturer, purchase order number, part number, heat number, extrusion drawing number, steel alloy grade, extrusion sequence number, chemical analysis, mechanical properties, lot quantity, part dimensions, heat treatment conditions, and certification that the material conforms to the requirements of this specification.

5. PREPARATION FOR DELIVERY

5.1 Packing. Extruded, drawn, and straightened AISI 4340 shall be packed in accordance with Level C of MIL-STD-163.

5.2 Marking for Delivery. Marking for shipment shall be in accordance with MIL-STD-163.

6. NOTES

6.1 Intended Use. Extruded, drawn, and straightened AISI 4340 products covered by this specification are intended primarily for use in highly stressed aircraft structures.

APPENDIX III

SPECIFICATION FOR PRECIPITATION HARDENING, PH14-8Mo STEEL, CHROME-NICKEL-MOLYBDENUM EXTRUDED TEE SHAPES

1. SCOPE

1.1 Scope. This specification covers PH 14-8 Mo alloy steel extrusions for aircraft quality parts.

1.2 Classification.

1.2.1 Physical condition PH 14-8 Mo extrusions shall be furnished in one of the following product forms:

a. Extruded and straightened
b. Extruded, drawn, and straightened
c. Extruded, drawn, straightened, and heat treated

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of the invitation for bids form a part of the specification to the extent specified herein:

a. Specifications

Military
MIL-I-6866B Inspection, Dye Penetrant

b. Standards

Federal

Federal Standard No. 48	Tolerances for Steel and Iron Wrought Products
Federal Test Method Standard No. 151	Metals, Test Methods for

c. Other Publications

MIL-STD-163	Steel Mill Products Preparation for Storage and Shipment
MIL-STD-183	Continuous Identification Marking of Iron

MIL-STD-430	Macrograph Standards for Steel Bars, Billets, and Blooms
Norair Process Specification IT-32.5	Ultrasonic Inspection
MIL-I-686BC	Magnetic Particle Method

3. REQUIREMENTS

3.1 Material

3.1.1 Chemical Composition. The chemical composition for PH 14-8 Mo shall be as specified in Table I.

TABLE I. CHEMICAL COMPOSITION

Element	Analysis (Range)
Carbon	0.03 - 0.043
Manganese	1.00 (max)
Phosphorus	0.040 (max)
Sulfur	0.030 (max)
Silicon	1.00 (max)
Nickel	6.50 - 8.00
Chromium	14.00 - 16.00
Molybdenum	2.00 - 3.00
Aluminum	.0.75 - 1.50

3.2 Grain Size. The grain size of the PH 14-8 Mo extrusion billets shall be predominantly Number 6 or finer.

3.3 The PH 14-8 Mo extruded, drawn, and straightened material shall meet the following mechanical properties shown in Table II after heat treatment, as specified in Section 3.4.

TABLE II. MECHANICAL PROPERTIES OF PH 14-8 Mo EXTRUSIONS

Property(1)	Condition A	Condition C
Ultimate Tensile Strength, ksi	135 (min)	200
Yield Strength, ksi	40 (min)	175
Elongation, % in 1-inch (min)	20	7

(1) The mechanical properties shown in Table II are to be measured in the longitudinal direction.

3.4 Heat Treatment. The extruded, drawn, and straightened parts shall be solution annealed at 1825F for seven minutes and air cooled (Condition A), austenite condition at 1700F for 15 minutes and air cooled (Condition A1700). Cool within one hour after completing austenitizing treatment to -100F. Hold at -100F for eight hours (Condition SR-100). Age at 950F one hour (Condition SR 950).

3.5 Dimensional Properties

3.5.1 Straightness. The extruded and drawn PH 14-8 Mo material shall be straight to 0.010 inch per linear foot.

3.5.2 Twist. The extruded and drawn material shall not exceed one degree per foot of length with a ten degree maximum twist.

3.5.3 Flatness. The extruded and drawn part shall not exceed a flatness of 0.010 inch per inch.

3.5.4 Extrusion Length. The length of an extruded and drawn part shall be as specified on an applicable extrusion drawing.

3.6 Extrusion

3.6.1 Extrusion Billet Temperature. The maximum extrusion temperature shall be 2100F.

3.6.2 Extrusion Ratio. The extrusion ratio shall be approximately 45 to 1, based on the container size of the extrusion press.

3.6.3 Structure. The extruded and drawn material shall be hot-cold worked sufficiently to produce a worked fibrous product.

3.7 Workmanship. The material shall be uniform in quality and condition; free from foreign material, internal, and external imperfections which are detrimental to the fabrication of parts or performance of the part in service. Spot grinding to remove minor defects from extruded parts is permissible provided specified minimum thickness tolerances are not exceeded.

3.8 Identification

3.8.1 Each extruded, drawn, and straightened part, unless otherwise specified, shall be in accordance with MIL-STD-183. The identification shall consist of the following:

a. Alloy Designation
b. Heat Number
c. Die Serial Number
d. Die Sequence Number
e. Extrusion Sequence Number
f. Name of Manufacturer

3.8.2 Extrusions or extrusion lots shall be marked or tagged with the following identification:

a. Specification Number
b. Heat Number
c. Quantity
d. Part Number
e. Extrusion Shape Number
f. Purchase Order Number

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection. Unless otherwise specified in the contract or applicable purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein.

4.2 Sampling Method. The product shall be selected randomly to represent each lot of material from one heat, offered for acceptance at one time.

4.2.1 Method. Samples shall be examined visually for conformance to the requirements of this specification.

4.3 Chemical Analysis. The chemical analysis of PH 14-8 Mo, as stated in Section 3.1.1, shall be determined in accordance with Federal Test Methods Standard No. 151. Chemical elements shall be determined by wet chemical, spectrographic, conductimetric, or other acceptable methods. In the event of dispute, analysis shall be by wet chemical techniques.

4.4 Tensile Tests. Two test samples shall be selected from a representative extruded and drawn part, selected at random from one lot of material. The test specimens shall be made in accordance with Method 211, Federal Test Method No. 151, Type F-2.

4.5 Heat Treatment. The heat treatment of PH 14-8 Mo steel shall be in accordance with Section 3.4 of this specification.

4.6 Grain Size. Specimens for grain size determination of the extrusion billets shall be determined in accordance with procedure B, C, or D, Method 311, Federal Test Method No. 151, and MIL-STD-430. Specimens for grain structure of wrought extruded products shall be determined by metallographic examination in accordance with Federal Test Method No. 151.

4.7 Surface Defects. Inspection for material flaws and surface defects shall be done in accordance with MIL-I-6868C and MIL-I-6866B specifications.

4.8 Dimensional Inspection. Dimensional inspection shall be done in accordance with Federal Test Standard No. 48 and shall satisfy the requirements of Section 3.5 of this specification.

4.9 Rejection. Extruded parts not conforming to this specification or authorized modifications shall be subject to rejection. Requalification of any rejected lot of material shall be at the discretion of the procuring activity. All requests for retesting of any material lot shall be in writing to the procuring activity.

4.10 Reports. The product supplier shall furnish three copies of a test report with each shipment. The report shall include: Name of manufacturer, purchase order number, part number, heat number, extrusion drawing number, steel alloy grade, extrusion sequence number, chemical analysis, mechanical properties, lot quantity, part dimensions, heat treatment, conditions, and certification that the material conforms to the requirements of this specification.

5. PREPARATION FOR DELIVERY

5.1 Packing. Extruded, drawn, and straightened PH 14-8 Mo shall be packed in accordance with Level C of MIL-STD-163.

5.2 Marking for Delivery. Marking for shipment shall be in accordance with MIL-STD-163.

6. NOTES

6.1 Intended Use. Extruded, drawn, and straightened PH 14-8 Mo products covered by this specification are intended primarily for use in highly stressed aircraft structures.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT This three-phase program has made available to the Air Force and industry processes for the manufacture of thin extruded, drawn, and heat treated tee shapes. In Phase I, a production manufacturing process for the extrusion of 0.062-inch-thick by 20-foot-long tee shapes in AISI 4340, PH 14-8 Mo, and 18% Ni maraging steel was developed at the H. M. Harper Company using a 1,200-ton Lowey-Hydropress. The extrusion procedures, glass lubrication, temperature, and post-extrusion thermal and mechanical property tests are described. The results of Phase I show a relationship between alloy content, extrudability, and ram speed. AISI 4340 is the easiest to extrude and has the highest ram speed of the three alloys extruded. 18% Ni maraging steel is the most difficult to extrude and has the lowest ram speed during extrusion. The ram speed and extrudability of PH 14-8 Mo is between the two. No relationship was found between ram pressure and any extrusion variable. Other Phase I activity included the development of a fast, inexpensive test method to select extrusion glass lubricants. The glass selection test method is a visual comparison of the flow, wettability, and surface reactions with known glass lubricants and provides a basis for selection. Flow stress and hot ductility data are reported. A reproducible drawing process was developed in Phase II to reduce the thickness of the 20-foot-long tee extrusions to a target thickness of 0.040 inch. The success of the drawing phase of the program is primarily attributed to the invention of an adjustable draw die system that completely eliminates the necessity for "pointing." One hundred fifteen extrusions were drawn in order to meet the thickness objective. The drawing procedures developed for the three alloys were conducted at room temperature; "warm" or "hot" drawing was not

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
heat treating steel						
hot ductility						
steel mechanical properties						
extrusion press and dies						
draw bench and dies						
Gleeble						
heat treating fixture						
extruding						
drawing						
straightening						
glass extrusion lubricants						
drawing lubricants						
AISI 4340						
PH 14-8 Mo						
18% Ni maraging steels						

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necessary. An annealing treatment was necessary to stretcher-straighten drawn AISI 4340 and PH 14-8 Mo. These thermal treatments do not lower the heat treat response of the alloys. Phase II results showed that stretcher-straightening 18% Ni maraging steel 0.040-inch-thick drawn tee shapes is possible at 1100F. The low work-hardening characteristics and small cross section of the drawn shapes limit room temperature straightening. A process to heat treat 20-foot-long by 0.040-inch-thick extruded and drawn AISI 4340, PH 14-8 Mo, and 18% maraging steel tee shapes was developed in Phase III. The heat treat response of the three alloys is adequate and exceeds the target mechanical properties for AISI 4340 and PH 14-8 Mo. A special tempering fixture also was developed to reduce any distortion to a minimum. A sub-zero (-100F) transformation unit also was designed and built to transform the PH-14-8 Mo 20-foot-long extruded and drawn shapes.